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INFLATABLE AIR DEFLECTORS FOR TRACTOR-TRAILERS

by

G. A. Gowing, eng., F. Gabbianelli, jr. eng., BEST TEST Inc.

Jacques Dupont, PNEUS METRIX

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17. Abstract

The purpose of this study was to investigate the feasibility of using inflated aerodynamic shapes to reduce drag and improve fuel economy of long-haul tractor-trailer vehicles. The first step was to evaluate 20 different configurations in wind tunnel tests on a 1/10 scale model. The results indicated potential fuel savings of up to 8.7% for devices attached at the tractor-trailer interface, and 1.6% at the rear of the trailer. An important finding was that even a less than ideal shape on the trailer front is much superior to current cab-mounted deflectors. Based on these results a full-scale prototype inflatable air deflector was fabricated for testing. The device reduced fuel consumption by 6% during controlled environment track testing at 100 km/h, and by 7% during a brief service trial between Montreal and Toronto, confirming wind tunnel test projections. There were no inherent operational problems and, provided that a simpler and lighter production model can be developed, inflatable devices appear to be a practical means of achieving fuel economy improvements superior to currently available deflectors.

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17. Résumé

Cette recherche avait pour objet d'étudier l'influence des structures gonflables de forme aérodynamique sur la résistance de l'air et, par conséquent, sur la consommation de carburant des ensembles routiers. L'étude a commencé par l'évaluation en soufflerie d'une vingtaine de maquettes à l'échelle du dixième. Les résultats montrent que des économies d'énergie sont réalisables et peuvent atteindre 8,7 p. cent dans le cas d'une structure placée entre le tracteur et la semi-remorque, et 1,6 p. cent dans le cas d'une structure placée à l'arrière de la semi-remorque. Autre constatation importante, une structure placée sur le devant de la semi-remorque donne des résultats beaucoup plus intéressants qu'un déflecteur sur cabine, même si elle n'est pas optimisée quant à la forme. Un prototype grandeur nature de déflecteur gonflable a été construit et utilisé dans des essais contrôlés sur piste à 100 km/h et dans un essai en service de courte durée entre Montréal et Toronto. Les économies constatées ont été de 6 et 7 p. cent, respectivement, ce qui confirme les prévisions tirées des essais en soufflerie. Sur le plan exploitation, aucun problème et, pourvu qu'on dispose d'un modèle plus simple et plus léger, il semble que les structures gonflables soient en voie de devenir un moyen pratique de réaliser des économies d'énergie supérieures à celles des déflecteurs actuels.

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1.0 PROJECT BACKGROUND

Most tractor-trailer vehicles currently utilized for commercial highway transportation were not designed with efficient aerodynamic performance in mind. On the contrary, the rectangular shapes of these vehicles are generally designed to provide maximum cargo space.

However, as fuel costs continue to rise, fleet operators have in recent years become more concerned with fuel economy. This created an enormous market for O.E.M. and after-market fuel economy devices. Amongst these devices are ''wind deflectors'', aerodynamic devices mounted on the tractor or trailer to reduce drag.

While some of these devices are moderately effective, aerodynamic performance of these devices is limited by their rigid construction. This is due to the fact that the device cannot be modified to optimize its effectiveness on different sizes and shape of vehicles.

Moreover, even the most recent, adjustable tractor mounted devices are basically designed for frontal effectiveness. However, research has shown that to reduce overall drag, it is important to seal the tractor-trailer interface to minimize the impact of side-winds.

Various devices have been projected to resolve these limitations. However, they are generally costly and limited in their application to a single operational tractor-trailer combination. An inflatable device appears capable of offering a cost effective, practical solution with tremendous flexibility in terms of its operational capabilities.

2.0 INTRODUCTION

The aim of this project was to verify the feasibility and the effectiveness of an inflatable air deflector concept. This was achieved by designing and fabricating a prototype to be used in a test program structured to measure the device's capability to reduce aerodynamic drag associated with tractor-trailers.

To demonstrate the device's effectiveness, the test program was divided into three separate phases. In each of these phases, the aerodynamic performance of the test device was monitored under different experimental conditions.

In the initial phase of the project, a wind tunnel test was performed on a 1/10th scale model of a tractor-trailer. During this test, several shapes of front and rear air deflectors were tested to determine the shape(s) to be adopted in the fabrication of the prototype. The factors governing this selection were the aerodynamic performance of the device as well as the feasibility and cost of its fabrication.

The wind tunnel testing also permitted an evaluation of the relative effectiveness of a front or rear or combination aerodynamic treatment. Finally, the test also defined to what degree the effectiveness of the rear treatment is dependent on the front end treatment.

In the second phase of the project, a controlled fuel economy test was conducted at the Motor Vehicle Test Centre, in Blainville. In this case, the specific purpose was to measure actual fuel savings resulting from the utilization of a prototype inflatable air deflector on typical long-haul tractor-trailers.

This controlled fuel economy test was conducted according to The Maintenance Council of the American Trucks Association/Society of Automotive Engineers (TMC/SAE) fuel consumption test procedure - Type II (SAE 1321). This test procedure was adopted principally because of its independence of environmental conditions, and also because it was specifically designed to test and evaluate various fuel economy modifications related to motor vehicles.

The results obtained relative to fuel consumption in this phase were compared with the results obtained during earlier wind tunnel testing at National Research Council (NRC) to determinate if a good correlation existed between the reduction in drag coefficients and relative improvement in fuel economy.

When the comparison between these results had been completed, the third and final phase was performed with the cooperation of Kingsway Transport. This consisted of a brief on-road trial of the inflatable air deflector in an existing transport fleet.

The purpose of the test was to measure the fuel saving attributable to the utilization of an inflatable air deflector on a tractor-trailer executing a typical long-haul route. This provided a comparison between results obtained during testing performed in a realistic environment with those results obtained during the two previous tests, where the environment was controlled.

For this on-road trial, the TMC/SAE fuel consumption test procedure - Type II was used as a general guideline, for the same reasons it was utilized during the tests executed at the Test Centre.

The results obtained from these three test phases were then analyzed in order to evaluate the true capability of the test device in reducing the aerodynamic drag on tractor-trailers, and its feasibility in terms of real-world application.

3.0 OBJECTIVES

- To investigate the feasibility of fabricating an inflatable air deflector prototype.

- To examine the difficulties encountered during the fabrication of the prototype.

- To confirm the effectiveness of the inflatable air deflector in reducing aerodynamic drag.

- To estimate the reduction in fuel consumption due to the utilization of an inflatable air deflector on tractor-trailers.

- To compare and verify the results obtained during the three individual phases of the test program. Wind tunnel, controlled track and on-road testing.

- To verify the general behaviour and comportment of the device when mounted on a tractor-trailer.

4.0 A DESCRIPTION OF THE DESIGN AND FABRICATION OF THE PROTOTYPE AERODYNAMIC DEVICE

4.1 Design of the device:

The device is formed from two basic elements, the exterior rubber envelope and a series of inflatable shaped sections.(a drawing of this is shown in Figure #1 on page 11.)

The rectangular exterior envelope is sized to the frontal dimensions of the truck tractor. Two flexible rubber membranes, joined for about 20 mm all around their perimeter form the actual envelope.

The envelope is attached to the face of the trailer -front by a series of fiber straps fixed to prepared attachment points around the periphery of the trailer face. The straps are linked to the envelope via load bearing metal rods which are inserted into a flap around the edges of the envelope. Openings are spaced along the flap to permit passage of the straps.

The inflatable shaped sections installed within the membranes of the envelope can be varied in terms of number and design depending on the desired concept. Each section is composed of several cylindrical elements which are deployed during inflation.

The sections themselves are basically composed of flat sheet material and the cylindrical elements are created by divisions within the section which when inflated create the cylindrical elements. This type of construction is typical of many inflatable products.

In the prototype device, three shaped sections were utilized. The first section has approximately the same dimensions as the exterior membranes. This section includes four cylindrical elements and is glued to the exterior membrane contacting the trailer face.

The second section, which is smaller than the first, includes only three cylindrical elements which are shorter than those of the first section. The two sections are held together by zipper connections located at appropriate attachment points relative to each section so that the cylinder elements fit in a pyramid fashion.

The third section is attached to the second in similar fashion and contains only two elements which once again are somewhat shorter than in the previous section.

A rubber air chamber is inserted inside each cylindrical element. The chambers are linked by air passages. As these chambers are inflated, they are controlled by the cylinder walls which themselves form the shaped section. Since the shaped sections and cylinder walls are basically not elastic, the assembly becomes quite rigid once inflated. Hence, the membrane can resist the aerodynamic forces imposed at highway speeds. In the event of failure of a rubber air chamber access is available via zipper openings located in areas of low strain within the cylindrical elements.

Once inflated, these sections form a pyramid-like shape constrained by the bottom section which is held by the exterior membrane to the trailer face. However, as the cylindrical

elements are inflated, certain irregularities appear in the exterior membrane which are undesirable both in terms of aerodynamics and appearance. This problem is easily resolved by slightly inflating the exterior envelope itself. The tension thus imposed eliminates irregularities resulting in a smooth, aerodynamic shape.

To disinflate the device, one simply opens the valves provided for each shaped section. Due to the pressure exerted by the exterior membrane as it endeavours to regain its initial form, the shaped sections empty quite rapidly. If the vehicle is in motion, the air pressure accelerates this process.

4.2 Fabrication of the device:

The selection of rubber material for use as the exterior membrane was based principally on its simple elastic properties. Other materials could have been used to form the desired shape, however, only rubber could provide the flexibility desired.

Such flexibility is necessary since the device must to some extent adjust to the tractor-trailer interface. The ability to smooth the overall shape of the device by injection of air within the membrane/shaped section cavity is also desirable.

Also, the ability of the rubber to regain its original shape when not under tension greatly simplifies the process of deflating the device. Moreover, once deflated, the

device can be left in place against the trailer face without any additional effort. The appearance of the device stowed in this fashion is acceptable and it imposes no limitations upon the otherwise normal use of the trailer.

The use of a non-elastic material would have necessitated a method of folding and retaining the exterior membrane once deflated and a secondary tensioning system to assist with the deflation of the device. In addition, the shape of the device once inflated would have been essentially fixed and the ability to obtain a smooth exterior profile greatly diminished.

As concerns the shaped sections, a number of different materials and processes were evaluated:

- Reinforced vinyl - ''Stedfast'' and ''Weblon''.
  The sections were relatively light and easy to fabricate but it proved impossible to achieve a solid bond between the wall and the dividing elements and both welded and glued seams failed after a certain period under pressure.

- Reinforced Hypolon.
  This material was very strong but also very heavy. Moreover, like the vinyl, the joints would not resist.

- Reinforced rubber canoe material.
  This material is very expensive (fifty dollars per square metre) and very heavy. Moreover, it proved difficult and time-consuming to work with as well as being rather delicate.

When these more sophisticated materials failed to provide a satisfactory solution, it was decided to evaluate a more simplistic approach. This decision hinged partly on the fact that the prototype was intended to evaluate the technical feasibility more than specific production methods.

Hence after consideration the walls of the shaped sections and cylindrical elements were fabricated of nylon material having 400 to 1000 deniers. Joints were created by reinforcing and double stitching the seams.

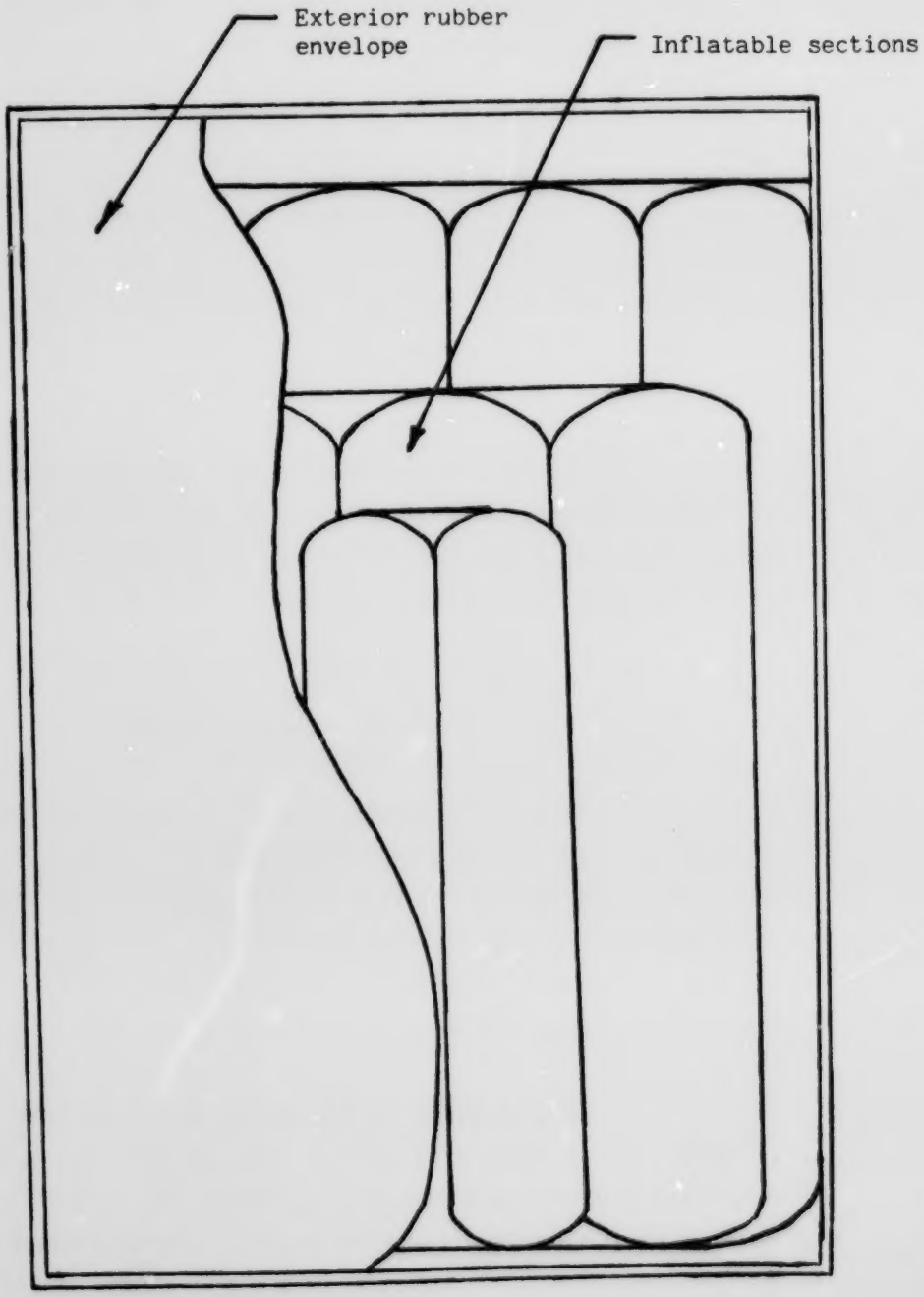
To provide air chambers common inner-tube type rubber was utilized. This material is relatively inexpensive, easy to work and bond and is quite resistant as well as providing excellent pneumatic properties. However, the curing process requires access to rather expensive machinery. The combination of nylon walls and rubber air chambers also added to the weight of the overall device.

Since the actual prototype had to withstand some severe winter operating conditions, this selection of materials was perhaps fortuitous.

Moreover, with additional development, it should be possible to simplify the device and reduce the overall weight.

FIGURE #1

Illustration of the inflatable air deflector



5.0 DESCRIPTION OF TESTS

5.1 Wind tunnel tests:

The wind tunnel testing was performed at the National Research Council, Montreal Road Laboratories in Ottawa. Dr. Kevin Cooper was responsible for directing activities in the low-speed wind tunnel during the test program.

The tests associated with this report were in fact integrated into a larger test program that Dr. Cooper was conducting concerning the aerodynamics of straight-body and tractor-trailer type trucks. In many ways, this facilitated the actual test program.

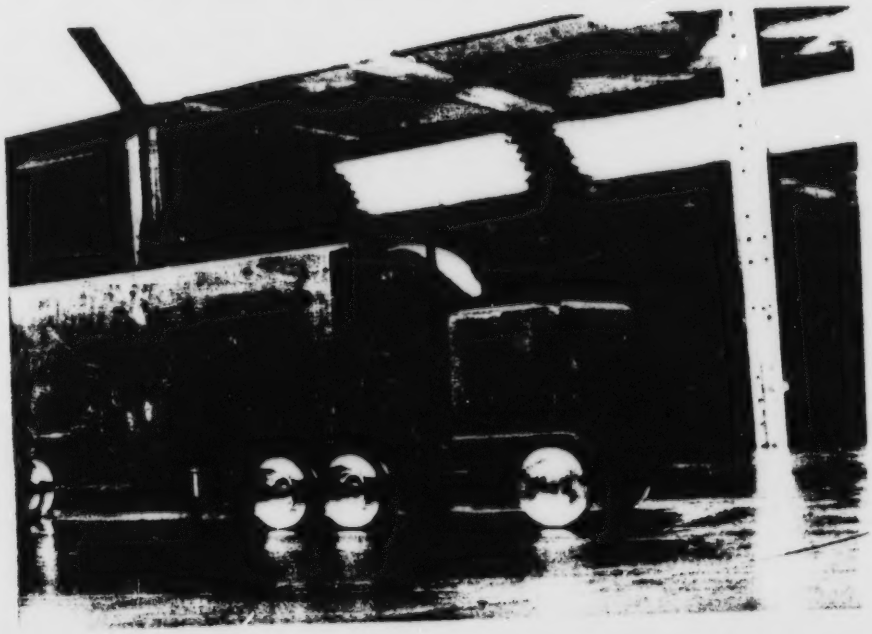
Indeed, consultations with Dr. Cooper prior to the test program were also of great assistance in defining a general test plan and approach concerning the fabrication of the scale-model aerodynamic devices.

5.1.1 Description of scaled-down model:

The truck model utilized during these tests was provided by NRC. It was a 1/10th model of a G.M. Astro 95 tractor and a standard 40ft van. This scaled-down model was an exact duplicate of the real tractor and trailer. Details like headlamps, mirrors and exhaust pipe were precisely duplicated on the tractor. The trailer model was also quite detailed and was smooth sided.

A photograph of the truck model equipped with treatment #2 is shown in Figure 2, on page 13. For a more complete description of the wind tunnel and model, reference #5 & 6 documents some of Dr. Cooper's prior work in relation to similar tests.

FIGURE #2



Truck model equipped with treatment no. 2

5.1.2 Description of air deflectors:

In addition to the standard tractor-trailer model used as a baseline, three basic frontal shapes (in eight variations) were tested as well as five rear profiles. Including test runs for the standard tractor-mounted deflector (this model was graciously provided by NRC), twenty-one test runs were conducted.

This included combinations of front and rear shapes as well as variations on certain shapes. Such variations were achieved by simply cutting and reshaping the wooden models as the testing progressed. A complete summary of wind tunnel data can be found in Annex B to this report.

We will limit our considerations in this report to those deflectors and combinations which produced definitive results. A brief description of each unit is provided below accompanied by a sketch of its shape relative to the truck model.

Treatment No. 1

This deflector is composed of two pieces, an upper and lower section. The shape was defined to simulate an ideal trailer mounted unit coupled with a lower section designed to block the tractor-trailer interface. This deflector could be considered ideal both in terms of frontal and side winds. It is referred to as Front Deflector No. 1A and 1B in Annex B.

Treatment No. 2

This deflector was intended to be less than ideal in that it did not seal perfectly with tractor-trailer edges. It did, however, seal the gap or tractor-trailer interface and its shape basically ressembled an inflatable device. This shape is referred to as Front Deflector No. 3 in Annex B.

Treatment no. 3

This deflector was modelled after state of the art tractor mounted deflectors and as previously indicated was fabricated by Dr. Cooper. It was intended to provide a comparison of effectiveness. It is referred to as NRC Deflector in Annex B .

Treatment no. 4

This shape was designed as a compromise rear shape. The intent was to seek the maximum drag reduction based on the shortest possible rear extension. This deflector is referred to as Rear Deflector No. 7 in Annex B .

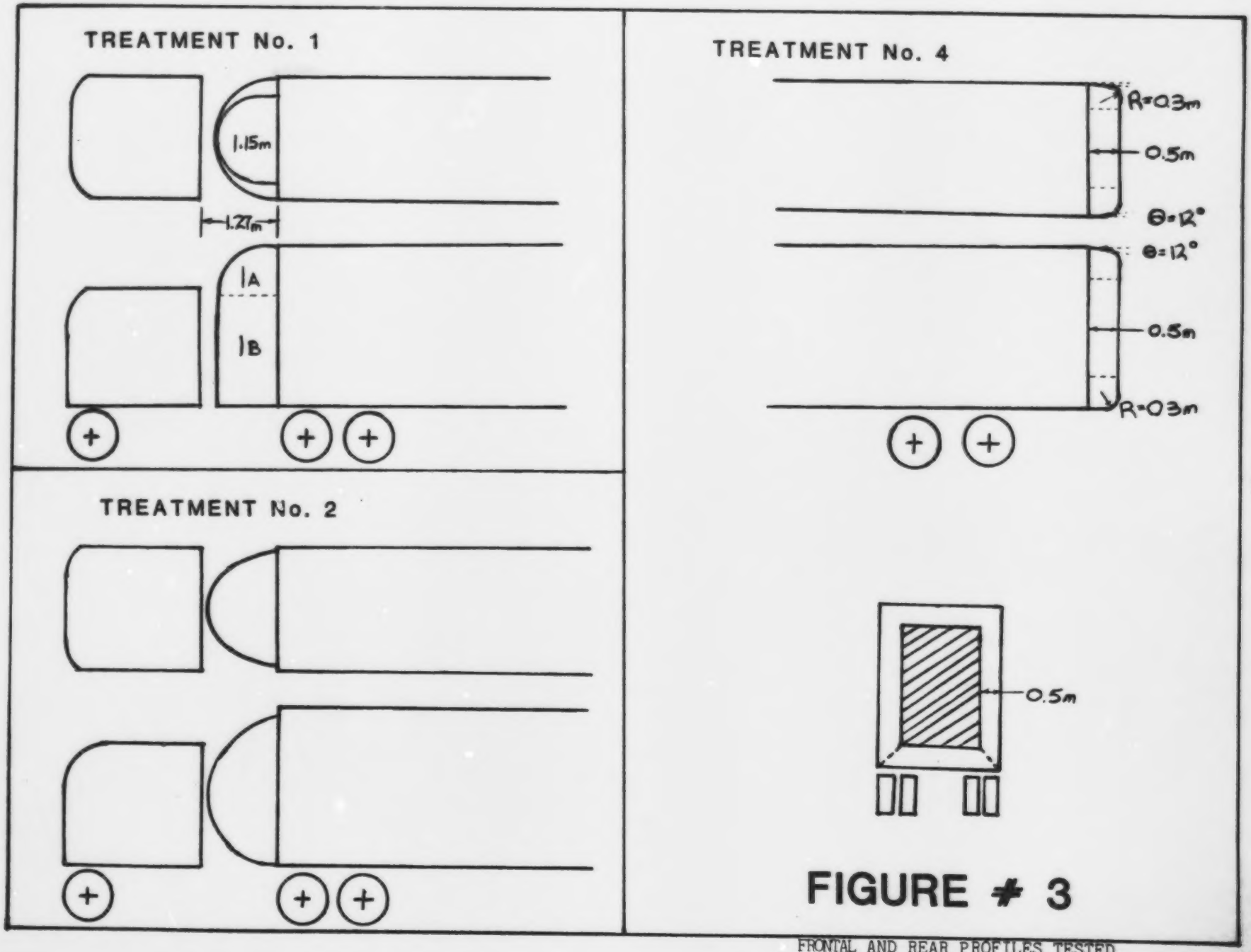


FIGURE # 3

FRONTAL AND REAR PROFILES TESTED
IN THE NRC LOW SPEED WIND TUNNEL

5.2. Controlled fuel economy test:

5.2.1 Description of test site:

The fuel consumption tests were conducted at Transport Canada Test Centre in Blainville, Quebec. This site was selected in order to provide a controlled environment. The test was conducted on the low speed track ''ALPHA''. This test track is a two lane closed oval with a typical asphalt road surface (skid no. 81) and a total length of 6.9 km. Traffic flow is counterclockwise only. A shematic layout of the site is provided in Annex A .

5.2.2 Description of tractor-trailers:

The SAE Type II test procedure requires the use of two similar tractor-trailers. Since the model used for wind tunnel testing was scaled on a G.M. Astro 95 cab-over tractor, it was considered desirable to utilize similar vehicles for testing. After considering cost and availability, two International Harvester vehicles were selected. These vehicles are physically similar to the G.M. Astro 95 in design.

Despite much careful preselection of the tractors, it was discovered when test personnel arrived to pick-up the vehicles at the rental agency, that the fuel pump on one vehicle was not in proper working order. An identical replacement vehicle also experienced mechanical problems. At this point, the only other vehicle available was a similar model but with some undesirable differences in characteristics.

Since a substantial portion of the test resources had already been committed, it was not considered advisable to delay or cancel the test. Moreover, while this substitution created a less than ideal situation, the differences are acceptable under the format of the Type II procedure. This substitution also necessitated some changes to the auxiliary fuel tank connections since the tank systems had been designed for the previously selected identical vehicles.

By the time all of the problems associated with the failure of the rental agency to produce the proper vehicles were rectified, over a full day had been lost.

The trailers utilized for the test were typical highway units. Although there were some differences in door openings, these were not considered critical to the test. However, both trailers did have significantly rounded forward corners. Since both were identical in this regard, this did not constitute a problem for the test. However, it is possible that they offered slightly less drag than the model used for wind tunnel testing. Hence, it is possible that this placed the test device at a slight disadvantage during these tests as compared to its wind tunnel counterpart.

The test load utilized for both vehicles was 11,636.6 kg , which meant a GVW of 24,700 kg for the control vehicle and 25,760 kg for the test vehicle.

One of the reasons for having selected this load was because consultation of literature pertaining to fuel economy testing on tractor-trailers revealed a characteristic GVW of 22,700 kg . Another reason being that this load is representative of typical fleet operations.

As described further in Section 5.2.4, for the purpose of the test, one vehicle is designated as the test vehicle and is equipped with the device to be tested. The second vehicle is designated as a control vehicle. Neither vehicle (tractor-trailer combination) may be modified during the testing period.

(Photographs of the tractor-trailer equipped with the inflatable air deflector can be seen in Figures #4 and #5 below)

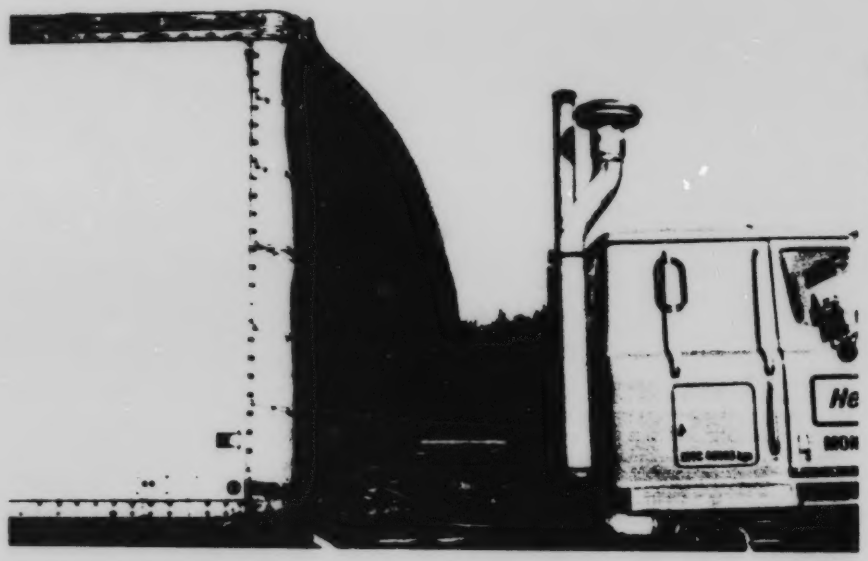


FIGURE #4

Tractor-trailer equipped with inflatable air deflector partially inflated

FIGURE #5

Tractor-trailer equipped with inflatable air deflector almost completely inflated

The following is a list of the characteristics of the control vehicle and test vehicle.

TABLE #1 Characteristics of tractors used in the controlled fuel economy test.

POWER UNIT	Control vehicle	Test vehicle
Unit number.	119205	119201
Make	International Harvester	International Harvester
Model	Transtar II (4070)	Transtar (4070)
Year	1979	1979
Number of axles	3 axles	3 axles
Number of drive axles	2 axles	2 axles
Engine make/model	Detroit G.M. 435	Cummings 350
Governed speed @ no load (high idle)	2100 RPM	2100 RPM
Rated power	435 hp	350 hp
Transmission make/model	Fuller 125/15	Fuller 125/15
Geared For	109.4 km/h (68 mph) at 2100 RPM in 15th gear	109.4 km/h (68 mph) at 2100 RPM in 15th gear
Differential make/model	Rockwell (44,000 lbs)	Rockwell (44,000 lbs)
Differential ratio	4.63 (19,958 kg)	4.63 (19,958 kg)
Tire size/type/make/model	11R22.5/radial/ Michelin/XM+S	11R22.5/radial Michelin/XM+S
Tire pressure	100 psi	100 psi

Note: The fan clutches of both vehicles were disconnected so as to reduce experimental errors.

TABLE #2 Characteristics of trailers used in the controlled fuel economy test.

TRAILER/BODY	Control vehicle	Test vehicle
Unit number	1006	1007
Make	Manac	Manac
Model	Highway doors 2.59m(102'')	Slide doors 2.59 m (102'')
Year	1978	1979
Type(van, flatbed, tank, etc.)	Van	Van
Type of side	Fiberglass	Fiberglass
Type of corner	Round	Round
Height	3.90 m (4ft off ground)	4m (4ft off ground)
Length	13.73 m (45 ft)	13.73 m (45 ft)
Tire size/type make/model	9.00-20	10.00-20
Pressure (cold)	80 psi	80 psi
Number of axles on trailer(s)	2 axles	2 axles
G.V.W. (measured on scale)	front 14,240 kg (31365.6 lb) rear 10,560 kg (23253.1 lb)	front 15,770 kg (34725.5 lb) rear 9,990 kg (21998 lb)
Kingpin setting	0.81 m (32 in)	0.91 m (36 in)
Cab-to-trailer gap	1.74 m (5'8.5'')	1.65 m (5'5'')

5.2.3 Description of the inflatable air deflector:

During the fuel consumption testing, two shapes of the inflatable air deflector were tested.

The first shape tested can be seen in Figure #6 on page 25. It is apparent from this illustration that the inflatable air deflector was only partially inflated.

However, in the Figure #7 on page 25, it is evident that the deflector is almost completely inflated and approaches the shape tested in the wind tunnel trials at NRC (treatment No. 2 - see Figure No. 3 on page 16).

The air deflector was not completely inflated in order to seal the gap between the tractor and the trailer, because of the concern that the prototype might not withstand the stress. Given the tight test schedule, it was considered undesirable to risk damaging the device since any delay for repairs would have greatly limited testing.

5.2.4 Description of test procedure:

This controlled fuel economy test was conducted according to the TMC/SAE fuel consumption test procedure - Type II (SAE 1321). This test procedure is specifically designed to evaluate fuel economy related modifications to vehicles. It is simple and accurate and is commonly used to evaluate truck aerodynamic devices. As distinct from other procedures, this procedure calls for the use of two vehicles, a control vehicle and a test vehicle. Measurements are based upon the relative

fuel consumption between the two vehicles thus minimizing the importance of ambient conditions and other daily site variations on test results.

The test procedure requires two segments: a baseline segment and a test segment. In the baseline segment, the baseline fuel consumption ratio between the control vehicle and the test vehicle is established. The baseline segment is conducted prior to the installation of the test device with both vehicles in their original state. This baseline segment normally consists of three runs where the ratio of the fuel consumption between the test vehicle and the control vehicle must be within a 2% range.

During the test segment, the fuel consumption of the test vehicle with the test device installed is compared to that of the control vehicle. This test segment must also consist of three test runs where the ratios of the fuel consumption between the two vehicles must be within a 2% range.

In this particular fuel consumption test, the test runs in the baseline segment and in the test segment consisted of 10 laps of the test track at 100 km/h , which is equivalent to a total distance of 60 km. However, before each test run, there was a 60 sec. idle following engine start-up and a 60 sec. idle at the end of each test run, before engine shutdown. The time it took to execute one test run was of the order of 44 minutes and 30 secs, including the 2 min. idle time. Therefore, as indicated in the SAE 1321 test procedure, the times of each test run should be within a range of $\pm$ 0.5%, or in this case $\pm$ 13 secs. Before actually commencing the test runs each day, a 45 minute warm-up period was allocated.

It will be noted that both the idle periods and warm-up period are slightly less than recommended by SAE 1321. This adjustment was necessary in order to maximize the number of test runs while allowing for exchange of fuel tanks and accomodating normal hours of operation at the test site.

As specified, the fuel consumption was measured gravimetrically. In this case, each truck was fitted with an 18 gallon portable fuel tank which was weighed before and after each run. This full weighing method has proven to be an accurate way of determining fuel consumption.

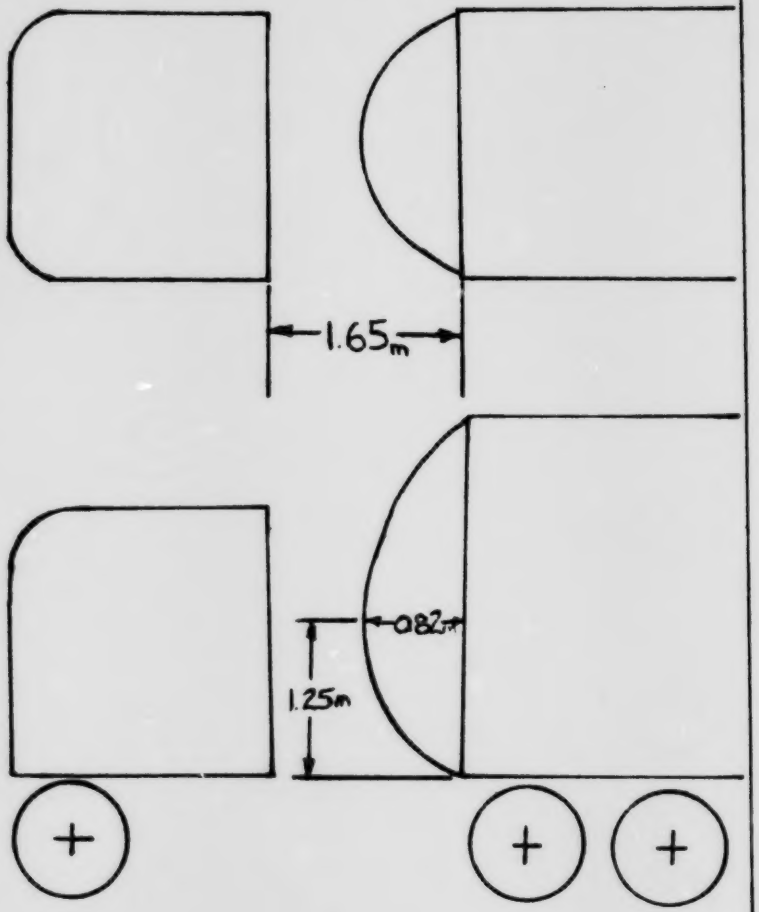
During each of the test runs, the fuel temperature and the weather data, i.e. as wind speed and direction, temperature, barometric pressure, and humidity were monitored and recorded. The reason for monitoring the fuel temperature was to assure it did not exceed the recommended temperature limit of 71°C as setforth in SAE 1321.

The lap times of each test run were also monitored. This is not a requirement in the SAE test procedure. However, these times were closely monitored since it was believed that significant fluctuations in the lap times might provoke errors in the fuel consumption measurements. Moreover, the physical layout at the test site permitted times to be monitored quite easily.

Analysis of the test results following completion of the tests has indicated that lap times may indeed be significant even when overall run times are within specified limits.

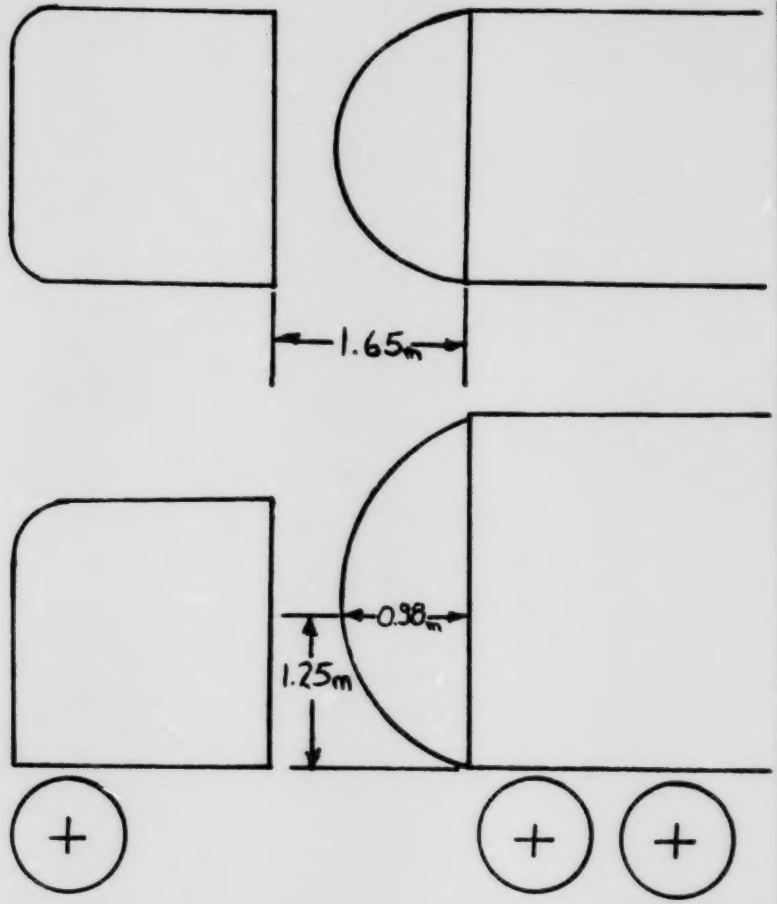
INFLATABLE AIR DEFLECTOR PARTIALLY INFLATED

FIGURE # 6



INFLATABLE AIR DEFLECTOR ALMOST COMPLETELY INFLATED

FIGURE # 7



The G.V.W. for both vehicles varied between 23614 to 35688 kg for the control vehicle and the test vehicle.

The reasons for having selected this G.V.W. was that it is representative of typical fleet operations, and also because this G.V.W. is similar to the one of the vehicles used during the on-road fuel consumption test.

As was the case in the fuel economy test, one vehicle is designated as the test vehicle and equipped with the device to be tested. The second vehicle is designed as a control vehicle. Neither tractor-trailer may be modified during the testing period.

5.3 On-road test trial:

5.3.1 Description of test site:

The test was performed on a long haul route between Montreal and Toronto or Toronto and Montreal, with a total distance of 565 km .

5.3.2 Description of tractor-trailers:

The SAE Type II procedure requires the use of two similar tractor-trailers. So therefore, due to their availability in the Kingsway fleet, two identical conventional International Harvester vehicles were selected. It is important to point out that in the two previous tests, cab-over models were utilized instead of a conventional model. The effect this has on the capability of the inflatable air deflector in reducing aerodynamic drag is unknown. However, judging by the results of the controlled fuel economy test and the on-road trial, it did not matter whether a cab-over or conventional type tractor was used, the results seemed more dependent on the tractor-trailer gap.

The trailers utilized for this test were the same units used in the fuel consumption test performed at the Test Centre. The trailers are highway type units with differences in door openings and significantly rounded forward corners. This does not constitute a problem as far as the test is concerned. However, as was the case in the controlled fuel economy test, it is possible that this places the test device at a slight disadvantage during this test as compared to the wind tunnel tests.

TABLE #3 Characteristics of tractors used in the on-road trial.

Power unit

Fleet: Kingsway Transport Date: 12/12 to 22/12, 1983

	Control vehicle	Test Vehicle
Unit number	51026	51009
Make	International Harvester	International Harvester
Model	F2500	F2500
Year	1980	1980
Number of axles	3	3
Number of drive axles	2	2
Engine make/model	Cummings 350	Cummings 350
Governed speed @ no load (high idle)	1950 RPM	2050 RPM
Rated power (bhp)	350 hp (kw)	350 hp (kw)
Rated speed	4000 RPM	4000 RPM
Transmission make/model	Fuller RT-12509	Fuller RT-12509
Geared for	100 (62.2 mph) km/h	100 (62.2 mph) km/h
	at 1950 RPM	at 2050 RPM
	in 10th gear	in 10th gear
Differential make/model	Rockwell	Rockwell
Differential ratio	4.11	4.11
Tires Front	11R24.5/RAD/Bridgestone/V-steel = 10.00RZZ/RAD/Michelin/XZA	
Rear	10.000 RZZ/RAD/Firestone/XR4 = 11R24.5/RAD/Goodyear/G167	
Tire pressure (cold)	95 psi	95 psi
5th wheel setting (express in (mm) the distance 5th wheel fulcrum is ahead or behind the center line of bogie)	--------- in (mm)	---------- in (mm)

Note: Both trucks have the same Snyder tanks.

Note: In areas where two units are shown (i.e. hp(kw)) circle the unit used

TABLE #4 Characteristics of trailers used in the on-road trial

Trailer/body

Pie IX Leasing Date: 12/12 to 22/12, 1983

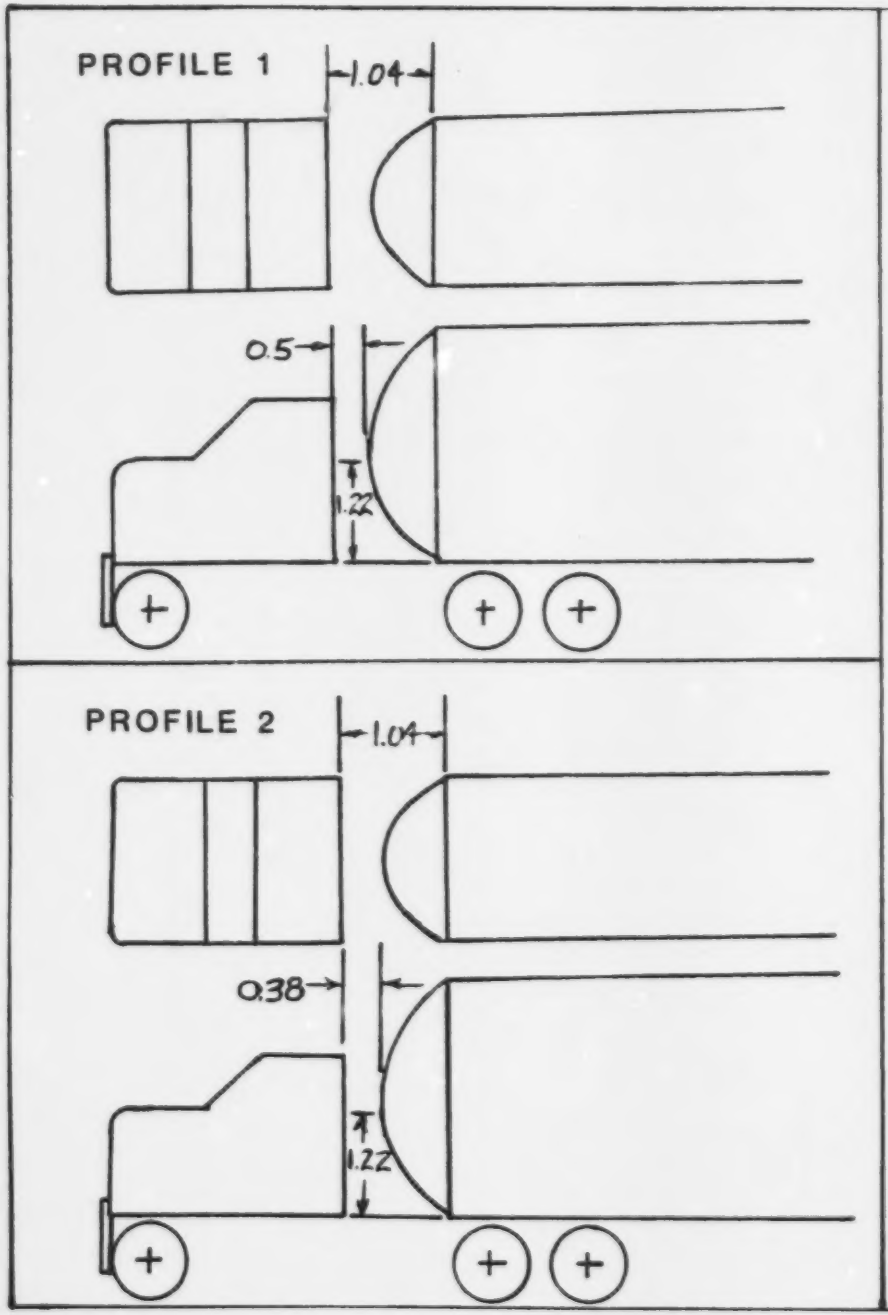
	Control vehicle	Test vehicle
Unit number	1006	1007
Make	Manac	Manac
Model	Highway doors (102'')	Slide doors (102'')
Year	1978	1979
Type (van, flatbed, tank, etc.)	Van	Van
Type of side	Fiberglass (smooth sides)	Fiberglass (smooth sides)
Type of corner	Rounded	Rounded
Height	3.90 m (4 ft off ground)	4 m (4ft off ground)
Length	13.73 m (45 ft)	13.73 m (45 ft)
Tires Front	11R20/ Michelin	10.00-20 Seiberling (right)
Rear	9.00-20/ Coop Highway frontier	Michelin and Firestone(left)
Pressure (cold)	75 psi	75 psi
Number of axles on trailer(s)	2	2
G.V.W. (measured on scale)	27248 kg (60000 lbs)	27248 kg (60000 lbs)
Kingpin setting	Set in (mm)	Set in (mm)
Cab-to-trailer gap	1.21 m (47.5 in)	1.04 m (40.75 in)

5.3.3 Description of the inflatable air deflector:

During this on-road trial, the shape of the air deflector remained essentially the same. These shapes can be seen in profiles no.1 through no. 3, in Figure no.8 on page 32 which represent test runs no. 1 through no. 3.

The air deflector was not completely inflated so as to seal the gap between the tractor and the trailer, because of the concern that the prototype would not withstand the stress. Given the nature of the test, it was considered undesirable to risk damaging the device because of the limited facilities in which repair can be accomplished on the road and also of the large delays this would cause.

During the installation procedure, the test device was punctured and even though repairs had been performed on the air deflector, small leaks were present in the device. However, the quantity of air escaping was so small that it did not constitute a problem for the test.



DIMENSIONS IN METRES

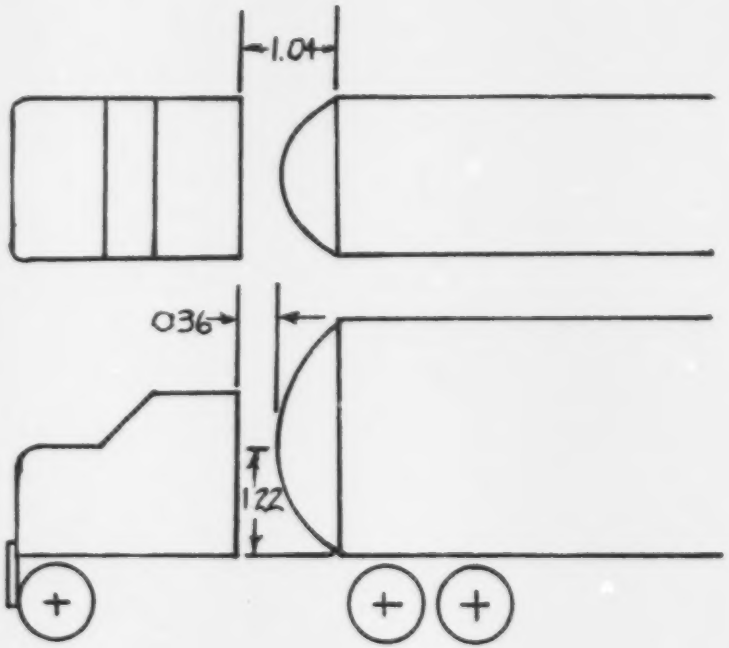


FIGURE #8

Inflation modes of the air deflector during the on-road trial.

5.3.4 Description of test procedure:

During the on-road trial, the TMC/SAE Fuel Consumption Test Procedure - Type II (SAE 1321) was utilized as a general guideline. This of course meant the use of two identical tractor-trailers to be used as a control vehicle and a test vehicle. Measurements are based upon the relative fuel consumption between the two vehicles thus minimizing the effects of ambient conditions or other site variations.

The test procedure requires two segments, a baseline segment and a test segment. In the baseline segment, the baseline fuel consumption ratio between the control vehicle and the test vehicle is established. The baseline segment is conducted prior to the installation of the inflatable air deflector on the test vehicle.

While in the test segment, the fuel consumption of the test vehicle with the air deflector installed is compared to that of the control vehicle in its original state.

The test runs executed during the baseline segment and the test segment consisted of a long haul between Montreal and Toronto or Toronto and Montreal. The total distance of each test run is approximately 565 km . These test runs were executed by both vehicles as if it was a routine haul for the transport company. However, during the testing period, the idle times of each vehicle were maintained equal, whenever possible.

Since the fuel saving resulting from the utilization of an inflatable air deflector on a tractor-trailer executing a routine long haul was desired, the requirements described in

the SAE test procedure, which states that the time of execution for the test runs be within ± 5% and the fuel consumption lies within a 2% range, was disregarded. The reason being that this does not represent what truely takes place in a normal fleet operation. Since poor road conditions and/or unexpected mechanical difficulties could cause fluctuations in the time of execution for a particular route.

A volumetric method was utilized to determine the fuel consumption of the tractor-trailers. This method consisted of filling the fuel tanks of each vehicle with cold fuel to a specific level. So therefore to determine the fuel consumption, the fuel tank was replenished to this designated level and the volume recorded after having executed a test run. In addition, the fuel temperature was recorded before and after each test run to compensate for the volumetric changes.

6.0 RESULTS AND CALCULATIONS

6.1 Wind tunnel tests:

6.1.1 General observations:

The test results are calculated through the following equation:

$$\text{Fuel savings} = 4.252 \times 10^{-4} \; A \; \Delta\overline{CD}$$

$$\text{Fuel saving} = 41.87 \; \Delta\overline{CD} \text{ at 100 km/hr}$$

This equation applies to the particular model utilized during the wind tunnel tests, for more details on the derivation of this equation, please consult reference # 1 . Another point to consider is that the fuel saving calculations are based on the assumption that the total vehicle resistance is divided evenly between the rolling friction and the aerodynamic drag for this particular vehicle at a speed of 100 km/hr, please consult reference # 6 for more information.

6.1.2 Results:

Air deflector no.	$\Delta\overline{CD}$ (55)	Fuel savings L/100 km at 100 km/hr	$ saving per 1979 hrs/ 161,000 km per SAE J-1376 Long Haul Cycle Fuel $0.55/litre
Treatment #1	0.174	7.28	6,005.
Treatment #2	0.149	6.24	5,148.
Treatment #3	0.098	4.10	3,383.
Treatment #4	0.033	1.38	1,139.
Treatment #3+4	0.181	7.58	6,254.

The results in Section 6.1.2 are the savings attainable in a 161,000 km duty cycle at 100 km/h .

It is evident from the results that the front air deflector offers a very interesting saving. These savings show that the air deflector can more than pay for itself in one year of operation.

The utilization of a rear air deflector can also provide interesting savings. However, the use of a rear air deflector will depend on its fabrication and installation costs, and operational problems. However, the potential savings are equivalent to or better than those attainable with other fuel economy devices currently in fleet use.

It is also important to note that the less than ideal front shape Treatment No. 2 achieves 86% of the drag reduction of the ideal shape. Moreover, this same shape is 52% better than the current state of the art tractor mounted deflector.

Also, contrary to initial predictions, the effectiveness of the rear deflector shape was not dependent upon the frontal treatment. This is of importance in terms of the applicability of the device.

6.2 Controlled track test:

6.2.1 General observations:

The test results as setforth in Section 6.2.2 and 6.3.2 are based upon the procedures outlined in SAE J-1321. The percentage fuel reduction is defined as :

$$\% \text{ fuel saved} = \frac{\text{Average baseline T/C ratio - average test T/C ratio}}{\text{Average baseline T/C ratio}}$$

For convenience, percentage results have also been transformed into Litre/kilometer savings based on a known fuel density of 0.8458 kg/litre.

Overall, the SAE J-1321 Type II test procedure functioned quite well. However, mechanical difficulties with the test vehicles and the heavy rain encountered on the first complete day of testing did create some difficulties. The mechanical difficulties and the resulting loss of time caused a compression in the test schedule. The heavy rain experienced during the first day's testing created an anomaly that was revealed once results were analyzed. As a result of this, following careful consideration , the baseline segment for the test vehicle is based upon only two runs instead of the normal three.

It was discovered that fluctuations in the test vehicle's lap times caused by the driver's accelerating and decelerating during the heavy rain on the two slight bends on the south side of the Test Centre's low speed track caused an acceptable variation in the T/C ratio despite the fact the overall run time and other criteria were acceptable. Following this discovery, individual lap times for both drivers were monitored continuously as well as overall run time. No further problems were encountered.

However, since the test device had already been installed on the test vehicle by the time this anomaly was discovered, and test time was becoming limited, it was decided not to attempt to replace the invalid baseline run.

Considering the extreme accuracy of all runs once lap time monitoring was instituted, it is believed that a third run would not have substantially effected the results. However, it is clear that when using this procedure, lap times as well as run times must be monitored continuously and with great care.

6.2.2 Results:

BASELINE SEGMENT

Control vehicle: Driver: Jacques Lachambre
Test vehicle : Driver: Claude Picard

Test run no.	T/C ratio	Check valid T/C ratios	Aver. baseline T/C
1	0.93		
2	0.883	x	0.88
3	0.877	x	

TEST SEGMENT #1 (partly inflated):

Control vehicle: Driver: Jacques Lachambre
Test vehicle : Driver: Claude Picard

Test run no.	T/C ratio	Check valid T/C ratios	Aver. test #1 T/C ratio
1	0.839	x	
2	0.850	x	0.841
3	0.835	x	

% fuel saved = 4.43%

Improvement in L/km = 0.028 L/km

Therefore, from this test data, it is estimated that this particular test vehicle equipped with an inflatable air deflector can produce a saving of $2,479.00 on a duty cycle of 161,000 km, assuming diesel is priced at $0.55/litre.

TEST SEGMENT #2:

Control vehicle: Driver: Jacques Lachambre
Test vehicle : Driver: Claude Picard

Test run no.	T/C ratio	Check valid T/C ratios	Aver. test #2 T/C ratio
1	0.82	x	
2	0.836	x	0.827
3	0.826	x	

% fuel saved = 6.02%

Improvement in L/km = 0.038 L/km

Therefore, from this test data, it is estimated that this particular test vehicle equipped with an inflatable air deflector can produce a saving of $3,382.60 on a duty cycle of 161,000 km, assuming diesel is priced at $0.55/Litre.

6.3 On-road trial:

6.3.1 General observations:

The test results were calculated using the same equation as in Section 6.2.1.

During this on-road trial, a malfunction in the fuel pump meter on the first series of test runs caused the test to be a complete loss.

As a result of this malfunction, a new series of test runs had to be executed the following week. During these test runs, mechanical difficulties and poor road conditions caused large idle times and also the operating speed had to be reduced as low as 50 km/hr for a lengthly period of time. This naturally means a reduction in fuel savings provided by the inflatable air deflector.

In the two final runs of the test segment, some difficulties were experienced. However, the results of these particular runs were considered in the test segment and compared to the baseline segment to obtain a fuel savings indicative of fleet operations.

The temperature of the fuel before and after each test run were similar of the control and test vehicle. Therefore, for all intents and purposes, the volumetric correction factor is negligible.

6.3.2 Results:

BASELINE SEGMENT

Control vehicle: Driver: Ghislain Deschaines
vehicle weight: run no. 1: 27,941.3 kgs
run no. 2: 27,242.8 kgs

Test vehicle: Driver: Hector Jubinville
vehicle weight: run no. 1: 27,152.0 kgs
run no. 2: 28,803.1 kgs

Test run no.	T/C ratio	Average baseline T/C
1	1.018	1.0165
2	1.015	

TEST SEGMENT

Control vehicle: Driver for test no. 1: Ghislain Deschaines
Driver for test 2 & 3: Jacques Lachambre

Vehicle weight: test run no. 1: 27,741.7 kgs
test run no. 2: 23,614.0 kgs
test run no. 3: 30,517.7 kgs

Test vehicle: Driver for test no. 1: Hector Jubinville
Driver for tests 2 & 3: Ghislain Deschaines

Vehicle weight: test run no. 1: 27,496.8 kgs
test run no. 2: 25,301.4 kgs
test run no. 3: 35,688.6 kgs

Test run no.	T/C ratio	Average test T/C
1	0.910	
2	0.969	0.945
3	0.955	

When correcting for the difference in the idle times in test runs no. 2 and no. 3,

The average test T/C ratio is 0.948.

Note: This is based on the fact that 1.5 gallons of fuel are consumed per hour when the vehicle is idling.

% fuel saved (uncorrected) = 7%
% fuel saved (corrected for idle times) = 6.74%

Improvement in L/km (uncorrected) = 0.033
Improvement in L/km (corrected) = 0.031

Therefore, from this test data, it is estimated that this particular test vehicle equipped with an inflatable air deflector can produce a saving of $2,922.00, assuming diesel is priced at $0.55/litre.

7.0 CONCLUSION

The results obtained during all three phases of the test program confirmed the effectiveness of the inflatable air deflector in reducing aerodynamic drag.

In wind tunnel tests at NRC, it was discovered that an 8.7% or 8 L/100 km improvement could be achieved with an optimal air deflector shape. However, it was quite impressive to note that a relatively simple shape which adequately filled the tractor-trailer interface could provide an improvement of 7.4%. This is 1 1/2 times the effectiveness of a standard air deflector. Therefore, because of its relatively simple shape, characteristic of an inflatable type device, and its good aerodynamic performance, this shape was selected for the fabrication of the actual prototype.

An important point to note with regard to the front end treatment is that the action of sealing the tractor-trailer interface produced an improvement of 3.5%. Moreover, sealing the gap seemed to improve the lateral stability of the vehicle in the presence of side winds. This was not the case for the standard air deflectors tested in the wind tunnel.

During the wind tunnel tests, a rear inflatable air deflector was tested for its aerodynamic performance. The improvement due to the installation of such a device was 1.7%. This is about 1/3 the effectiveness of the frontal air deflector.

However, this is not at all negligible when compared to other fuel economy modifications currently on the market.

One other point of particular interest to note about the rear end treatment is that its wind tunnel performance was relatively independent of the front end treatment of the vehicle.

It is well known that the results obtained during wind tunnel testing are theoretical and may vary when the device is placed in actual use due to variations in environmental and road conditions. However, when a prototype ressembling the simplified frontal shape of the wind tunnel experiment was tested at the Motor Vehicle Test Centre in Blainville, the device provided a fuel economy of 4.43% and 6.02% in the two inflation modes.

This result generally confirms the findings of the wind tunnel testing. Moreover, considering that the device while approaching the shape of the wind tunnel forms did not seal the tractor-trailer interface completely, this level of performance is extremely good. In fact, as was mentioned earlier, the sealing of this interface alone produced an improvement of about 3.3%. Hence, the results seem to indicate quite clearly that had the device, while maintaining the same shape, been capable of sealing the interface, the improvement would have corresponded very closely with the wind tunnel results. Hence, one can anticipate that the device has the potential to achieve a 8% fuel reduction.

It should be noted that the device was not inflated so as to completely seal the tractor-trailer gap because of stress limitations related to its fabrication.

Moreover, by way of comparison, the test device even in this less than ideal format far exceeded the performance of the standard tractor mounted deflector based on the wind tunnel results (6.02% versus 4.9%).

In addition to its aerodynamic performance, it must also be noted that the device did not create any problems with respect to normal operation of the vehicle. There was no sign of instability, no additional noise. In fact, the general opinion of the test driver was that the device seemed to improve the feel of the vehicle. While highly subjective, this is nevertheless a most encouraging comment.

Due to the tight test schedule and the time lost because of mechanical difficulties with one of the vehicles, it was impossible to verify the performance of the device when installed at the rear of the vehicle. But given the performance of the device on the front of the vehicle, it may well be justified to assume that a front and rear combination could provide a 9% fuel reduction under equivalent test conditions.

The correlation between the results obtained during the wind tunnel testing and the fuel consumption test led the project into its final phase, which consisted of an on-road trial. During this trial, an improvement of 7% was easily achieved from the utilization of an inflatable air deflector. This result confirms the findings of the previous wind tunnel tests and track fuel consumption tests.

This performance is extremely good when considering the low operating speed and the large idle times which took place in the final test runs, due to poor road conditions. These final test runs were nevertheless incorporated into the test segment to produce a fuel saving which can be expected to be typical of an actual fleet operation.

Another factor of interest is that as in the fuel consumption tests, the device was not inflated to the point of sealing the interface between the tractor and the trailer. However, the gap was somewhat smaller during this on-road trial, which resulted in a slightly better fuel saving than what was monitored in fuel consumption tests.

As in the case of the track fuel consumption test, the normal operation of the vehicle was not adversely affected by the inflatable air deflector. Instead, the test drivers felt that the device seemed to improve the feel of the vehicle.

As a final note, when the test results of this on-road trial were compared to the wind tunnel results of standard tractor mounted air deflector, this inflatable air deflector in a less than ideal format exceeded the performance of the standard tractor mounted deflector (7% versus 4.9%).

During the test program, it was evident that to commercialize this inflatable air deflector, a second generation device must be created that is lighter and simpler than the existing prototype.

The prototype that was tested was designed and fabricated much stronger than necessary for the operational conditions to which it would normally be exposed. The rigidity needed could be achieved by replacing the inner air bladders with nylon envelopes. This provides an inner air chamber with the elasticity and the rigidity to withstand the aerodynamic forces involved.

Therefore, the elimination of the inner air bladders could provide:

1. a simplification of the device,
2. a reduction in the weight of the device,
3. a reduction in the cost of fabrication,
4. a greater elasticity, permitting a greater extension of the device.

The attachment mechanism should also be further refined and simplified in order to reduce the time and labour involved in the installation.

Therefore, based on the results of the study, it can be concluded that an inflatable aerodynamic device such as that tested is effective, economic, practical, and with suitable redesign for production, it could be applicable to:

- tractor-trailers: the frontal or possibly the rear area of the trailer could be equipped with an inflatable air deflector either permanently or temporarily affixed.

- containers: similarly, the frontal area of the container could be equipped with this device, temporarily affixed.

In addition, it is possible that other applications of such a device are feasible, including intercity buses, since the device seems to adapt easily and produces on-the-road results that correspond closely with theoretical estimate.

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3. Henry E. Seiff, ''Testing for Improved Truck and Bus Fuel Economy'', SAE Paper no. 821257, presented at Truck & Bus Meeting & Exposition, Indianapolis, Indiana, November 8-11, 1982.

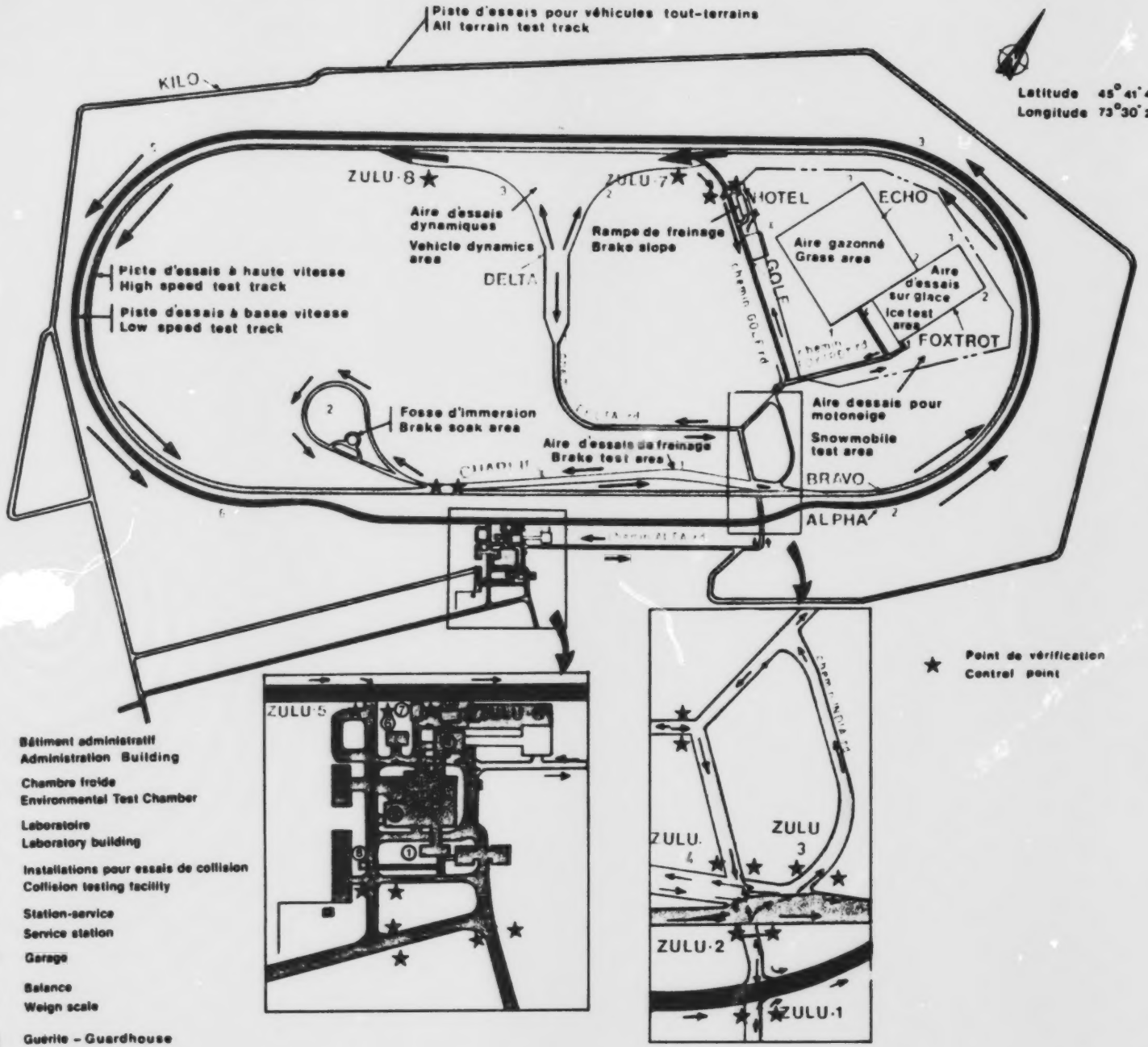
4. James N. Kettinger, ''Tractor-Trailer Fuel Savings with an Aerodynamic Device - a Comparison of Wind Tunnel and On-Road tests'', SAE Paper no. 820376, presented at International Congress & Exposition, Detroit, Michigan, February 22-27, 1982.

5. K.R. Cooper, ''The Wind Tunnel Simulation of Surface Vehicles'', Ottawa, Canada, April 1982.

6. K.R. Cooper, ''The Wind Tunnel Testing of Heavy Trucks to Reduce Fuel Consumption'', Ottawa, Canada.

ANNEX A.

Diagram of Motor Vehicle Test Centre,
Transport Canada, Blainville


Piste d'essais pour véhicules tout-terrains
All terrain test track
KILO
Latitude 45° 41' 45"
Longitude 73° 30' 2"
ZULU·8
ZULU·7
HOTEL
ECHO
Aire d'essais dynamiques
Vehicle dynamics area
Rampe de freinage
Brake slope
Aire gazonné
Grass area
Piste d'essais à haute vitesse
High speed test track
DELTA
GOLF
Aire d'essais sur glace
Ice test area
Piste d'essais à basse vitesse
Low speed test track
FOXTROT
Fosse d'immersion
Brake soak area
Aire d'essais pour motoneige
Snowmobile test area
Aire d'essais de freinage
Brake test area
BRAVO
ALPHA
ZULU·5
ZULU·6
ZULU·4
ZULU 3
ZULU·2
ZULU·1
Point de vérification
Control point
① Bâtiment administratif
Administration Building
② Chambre froide
Environmental Test Chamber
③ Laboratoire
Laboratory building
④ Installations pour essais de collision
Collision testing facility
⑤ Station-service
Service station
⑥ Garage
⑦ Balance
Weigh scale
⑧ Guérite – Guardhouse

A1

ANNEX B.

Wind Tunnel Test Results

ANNEX B.

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1.0 Summary of wind tunnel test results

PNEUS METRIX PROJECT

TREATMENT NO.	TEST NO.	C_{D_0}	$\overline{C_D}_{(55)}$	$\Delta \overline{C_D}_{(55)}$
Standard tractor-trailer	2	0.847	0.971	--
Front # 1 B	3	0.800	0.902	0.069
Front # 1A + 1 B	4	0.696	0.797	0.174
Front # 1 A	5	0.711	0.857	0.114
Front # 3	6	0.697	0.822	0.149
Front # 3, Rear # 5	7	0.686	0.804	0.167
Front # 3, Rear # 7	8	0.668	0.790	0.181
Front # 3, Rear # 6	9	0.679	0.797	0.174
Front # 3, Rear # 8	10	0.680	0.803	0.168
Front # 3, Rear # 4	11	0.673	0.796	0.175
Front # 3, standard deflector	12	0.676	0.820	0.151
Standard deflector	13	0.678	0.873	0.098
Standard deflector, front # 9	14	0.674	0.859	0.112
Standard deflector, front # 2	15	0.661	0.818	0.153
Front # 2	16	0.788	0.902	0.069
Front # 1 A, Front # 2	17	0.659	0.781	0.190
Front # 1 A (on tractor), Front # 2	18	0.647	0.812	0.159
Front # 1 A (on tractor)	19	0.662	0.851	0.120
Rear # 7	20	0.822	0.938	0.033
Front # 10	21	0.784	0.920	0.051

2.0 Description of configurations tested

2.1 Description of frontal profiles:

Treatment no. 1:

This deflector is composed of two pieces, an upper and lower section. The shape was defined to simulate an ideal trailer mounted unit coupled with a lower section designed to block the tractor-trailer interface. This deflector could be considered ideal both in terms of frontal and side winds. It is referred to as Front Deflector no. 1A and 1B in the wind tunnel report. This shape is illustrated in drawing no. F1 seen on page B4.

Treatment no. 2:

This deflector is illustrated in drawing no. F2 on page B5 However, to reduce the number of pieces being utilized during the wind tunnel tests, the lower section of Treatment no. 2 was used in conjunction with Treatment no. 1A to complete the air deflector package.

During the testing program, Treatment no. 1A was also fixed to the roof of the tractor while the lower section of Treatment no. 2 remained in its standard position. This combination is practically equivalent to Treatment no. 2 illustrated on drawing no. F2. Results of this deflector can be seen in test no. 18, on page B1.

Treatment no. 3:

This deflector was intended to be less than ideal in that it did not seal perfectly with tractor-trailer edges. It did, however, seal the gap or tractor-trailer interface and its shape basically ressembled an inflatable device. This shape is illustrated in drawing no. F3, on page B6.

Treatment no. 9:

Treatment no. 9 is a simplified version of Treatment no. 1B. This variation was achieved by reducing the width of Treatment no. 1B so as to permit the deflector to be attached to the rear of the tractor rather than the trailer. This is illustrated in drawing no. F1 on page B4 . Results obtained with this deflector can be seen in test no. 15, on page B1.

Treatment no. 10:

This treatment is also a simplified version of Treatment no. 1B. However, in this case, the deflector was modified in a cylindrical fashion, as can be seen in drawing no. F4 on page B7.
See test no. 21 for results (on page B1).

Standard deflector:

This deflector was modelled after state of the art tractor mounted deflectors and as previously indicated was fabricated by Dr. Cooper. It was intended to provide a comparison of effectiveness.

2.2 Description of rear profiles:

Treatment no. 4:

This deflector is illustrated in drawing no. R1 on page B8.

Treatment no. 5:

This deflector is illustrated in drawing no. R2, on page B9.

Treatment no. 6:

This rear deflector is based on drawing no. R3 with the exception that the radius of the rounder corners is slightly larger.

Treatment no. 7:

This shape was designed as a compromise rear shape. The intent was to seek the maximum drag reduction based on the shortest possible rear extension. This deflector is illustrated in drawing no. R3 on page B10.

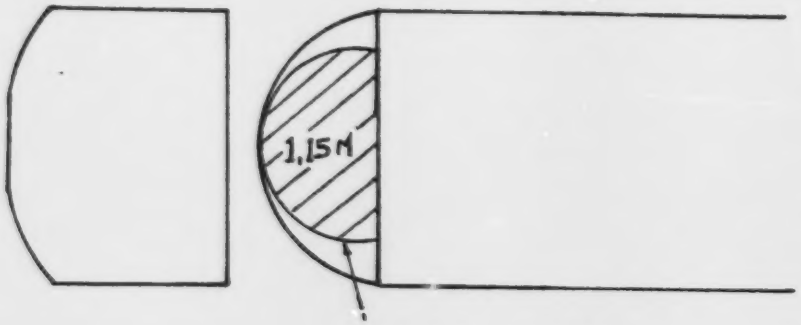
Treatment no. 8:

This deflector is illustrated in drawing no. R4 on page B11.

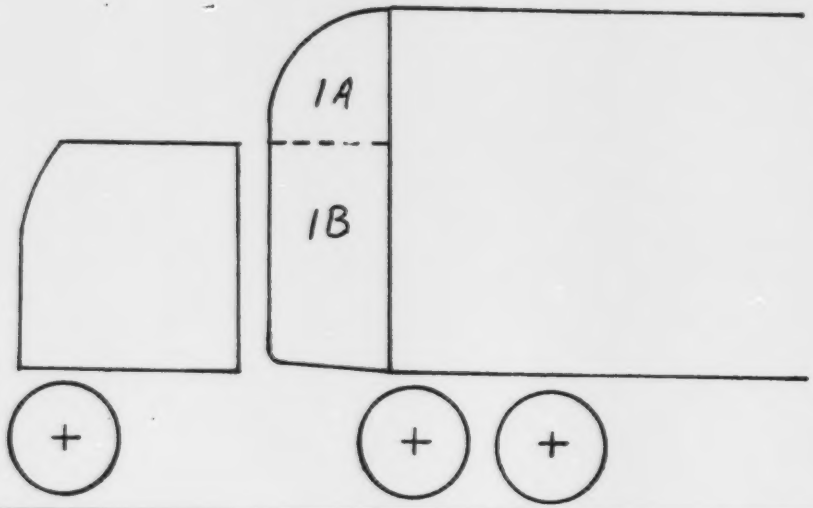
PNEUS METRIX PROJECT

Frontal Profile

TREATMENT No. 1A + 1B AND No. 9



Treatment No. 9 – Reduced Version of Treatment No. 1B



Drawing No. F1

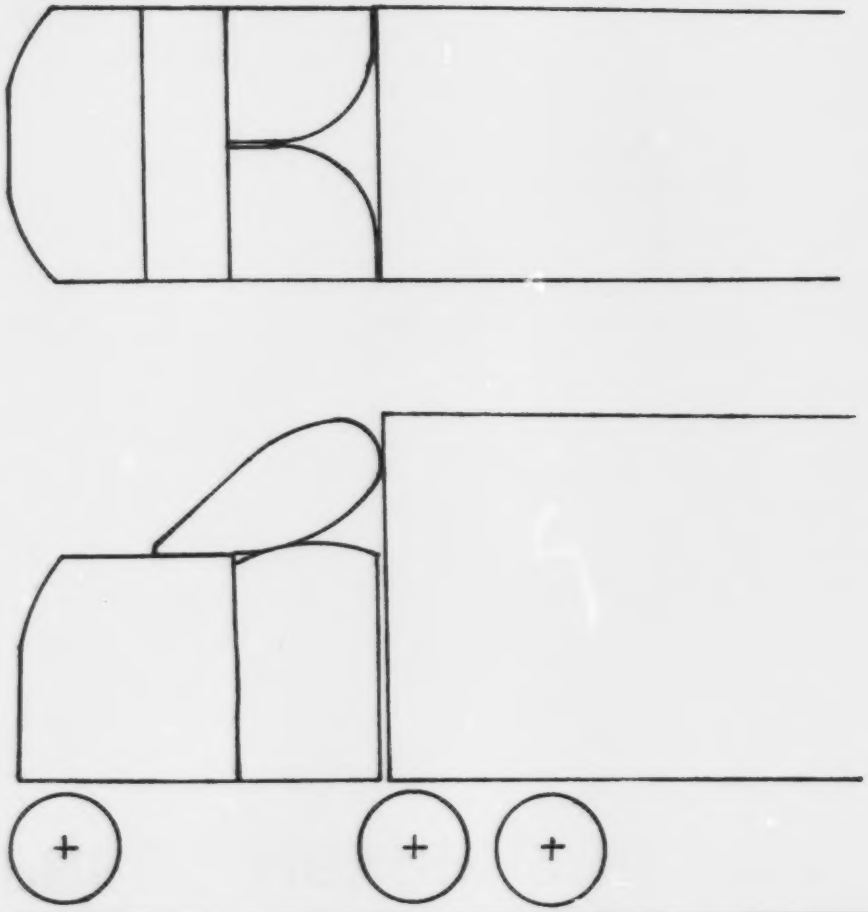
ING
28 FEV/83

BESTTEST

PNEUS METRIX PROJECT

Frontal Profile

TREATMENT No. 2



Drawing No. F2

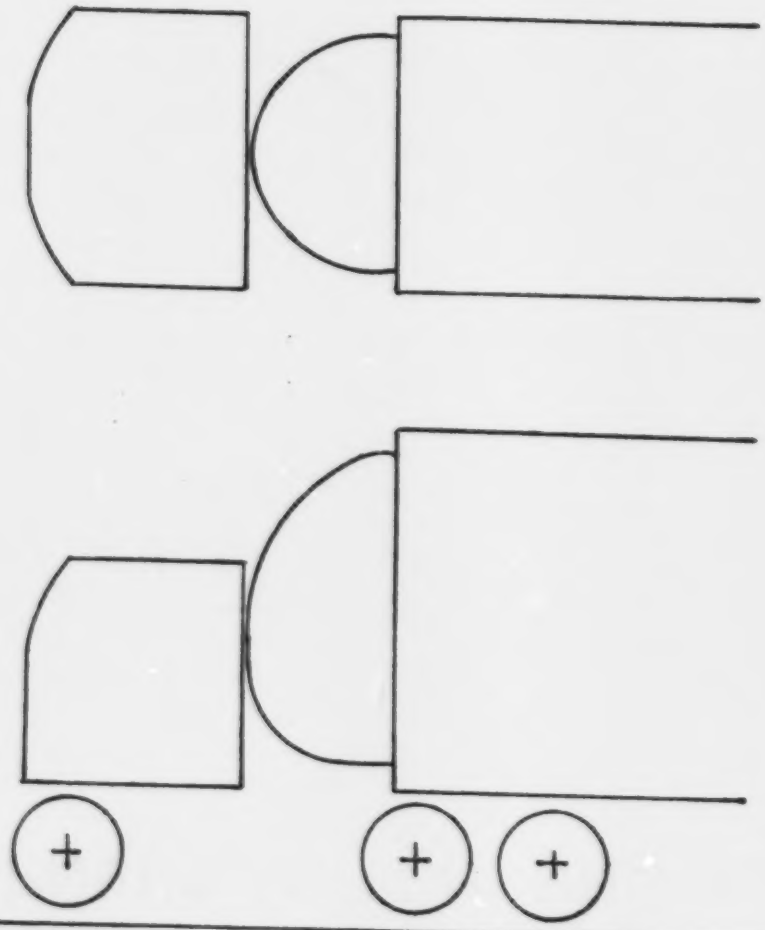
ING
28 FEV/83

BESTTEST

PNEUS METRIX PROJECT

Frontal Profile

TREATMENT No. 3



Drawing No. F3

31 Mars/83

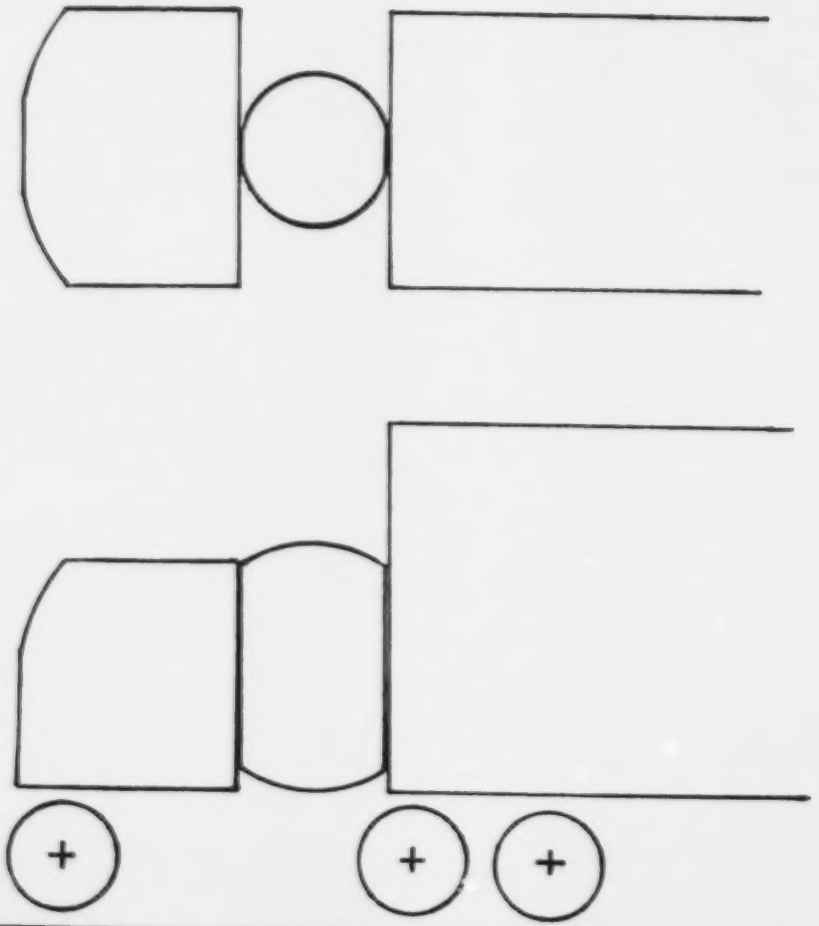
BESTTEST

B6

PNEUS METRIX PROJECT

Frontal Profile

TREATMENT No. 10



Drawing No. F4

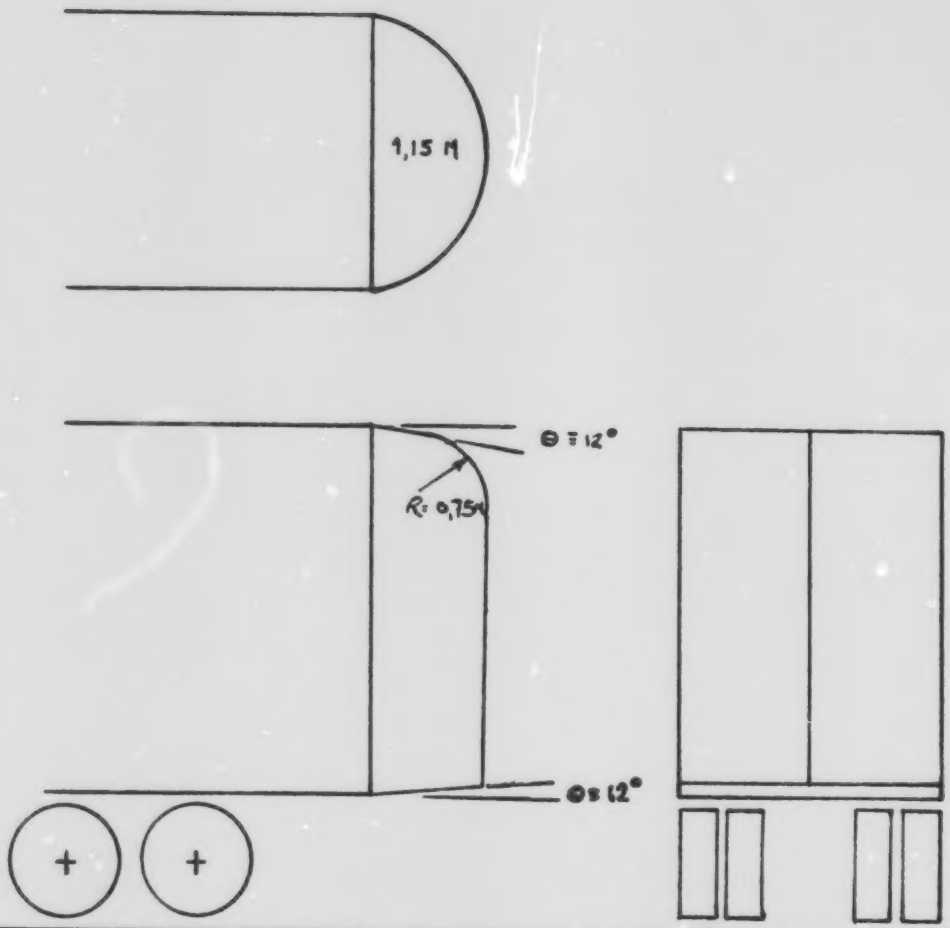
89 Feb '93

BESTTEST

PNEUS METRIX PROJECT

Rear Profile

TREATMENT No. 4



Drawing No. R1

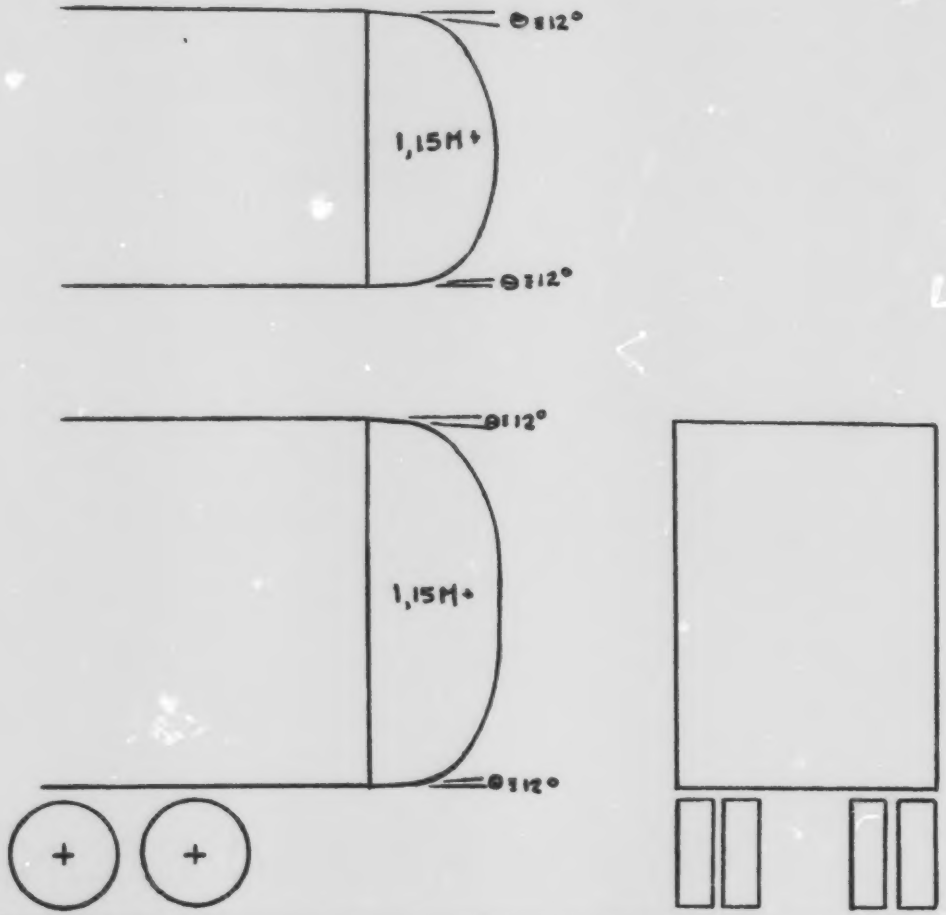
ING
29/FEV/83

BESTTEST

PNEUS METRIX PROJECT

Rear Profile

TREATMENT No. 5



Drawing No. R2

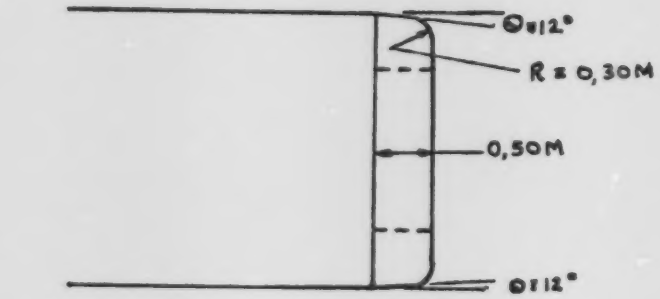
ING
29 Feb/88

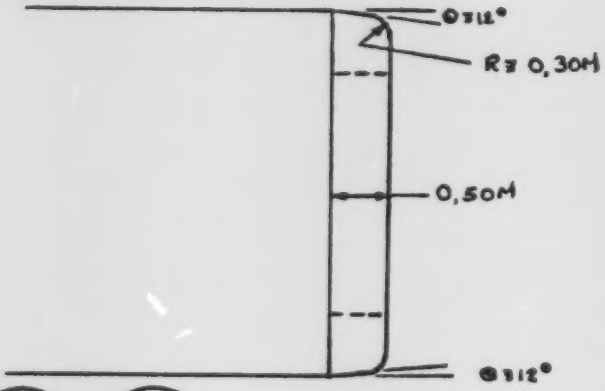
BESTTEST

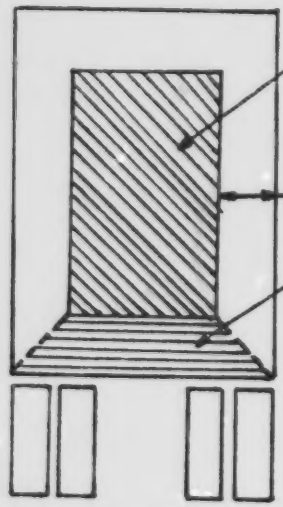
PNEUS METRIX PROJECT

Rear Profile

TREATMENT No. 6 and 7







Removable Section

Removable Subsection

Drawing No. R3

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28 FEV / 83

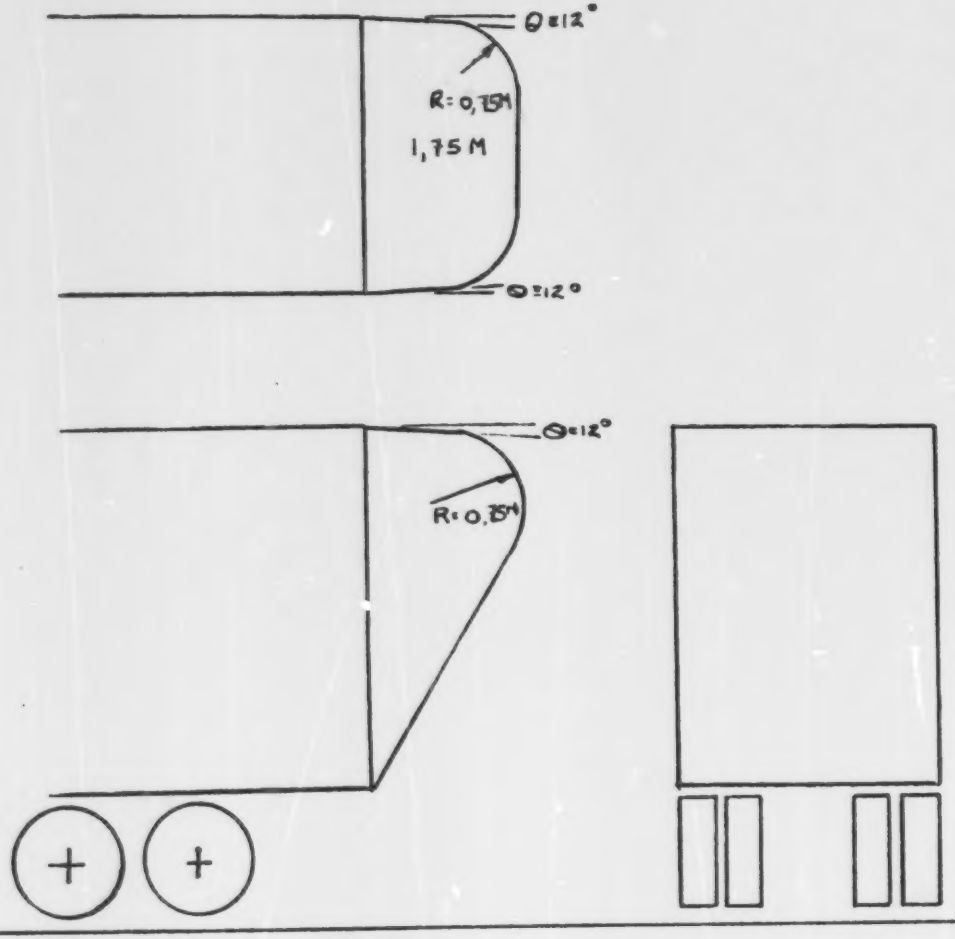
BESTTEST

B10

PNEUS METRIX PROJECT

Rear Profile

TREATMENT No. 8



Drawing No. R4

INS
CNRS

BESTTEST

B11

4.0 Force and moment coefficients versus yaw angle

RUN NUMBER 2 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, STANDARD FRONT

18-MAR-83 09:25:39 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

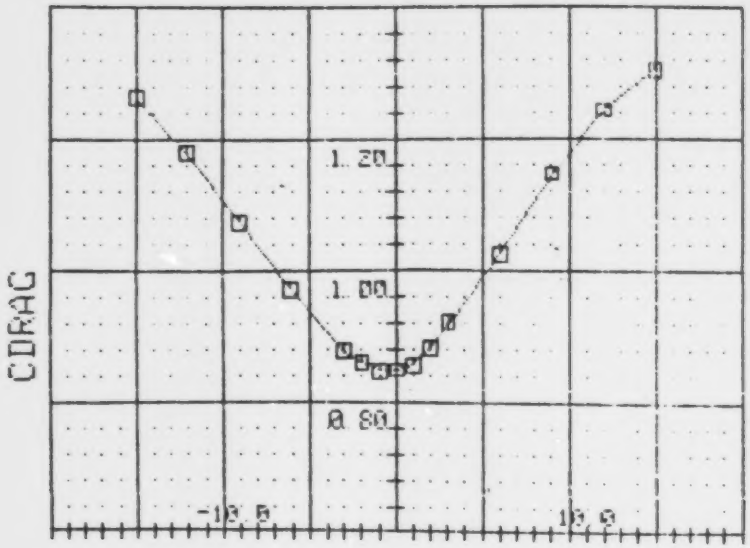
Velocity= 238.1 ft/sec Re= 1.216

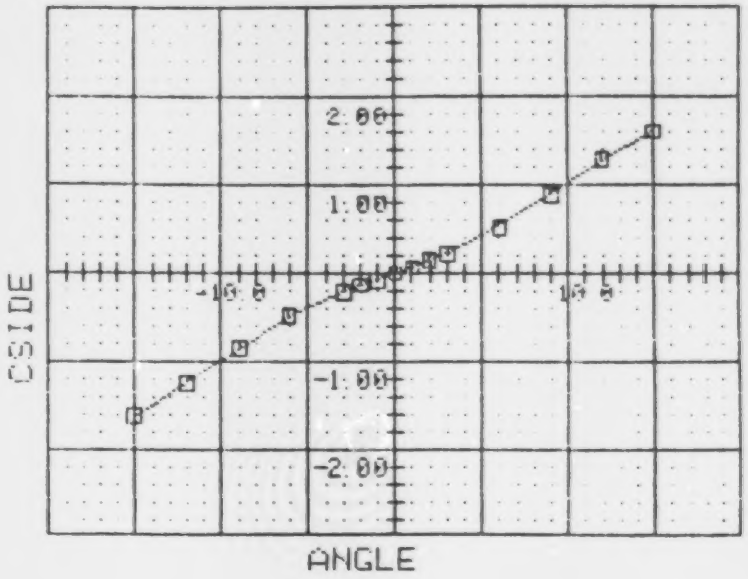
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.02	-2.717	2.127	-1.634	5.402	-0.876	1.263	1.12
-12.02	-1.963	1.659	-1.252	4.640	-0.740	1.178	1.10
-8.98	-1.240	1.175	-0.867	3.731	-0.548	1.073	1.08
-6.09	-0.664	0.717	-0.508	2.920	-0.374	0.971	1.07
-2.97	-0.281	0.292	-0.224	2.323	-0.270	0.875	1.06
-1.99	-0.187	0.200	-0.147	2.210	-0.253	0.858	1.06
-0.97	-0.093	0.029	-0.082	2.129	-0.254	0.847	1.06
0.05	-0.006	-0.071	-0.010	2.133	-0.249	0.847	1.06
0.99	0.072	-0.169	0.055	2.179	-0.257	0.855	1.06
1.98	0.167	-0.279	0.134	2.287	-0.271	0.881	1.06
3.03	0.264	-0.388	0.211	2.473	-0.287	0.919	1.06
6.00	0.683	-0.793	0.508	3.120	-0.391	1.024	1.08
9.01	1.300	-1.338	0.886	4.014	-0.534	1.145	1.09
11.99	1.996	-1.805	1.265	4.810	-0.672	1.244	1.11
14.99	2.615	-2.326	1.595	5.396	-0.704	1.305	1.12

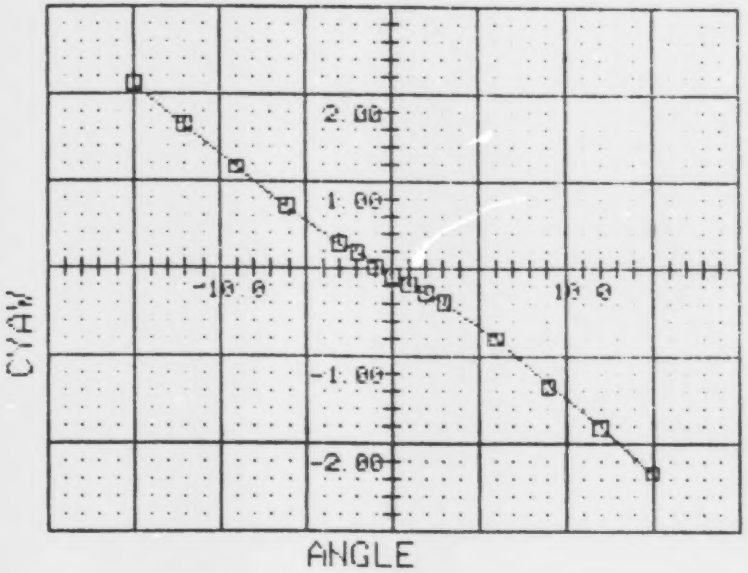
Wind Averaged Drag Coefficient at 55 mph = 0.971

Run 2

ASTRO 95, STANDARD FRONT







B13

RUN NUMBER 3 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 1B

18-MAR-83 09:32:23 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

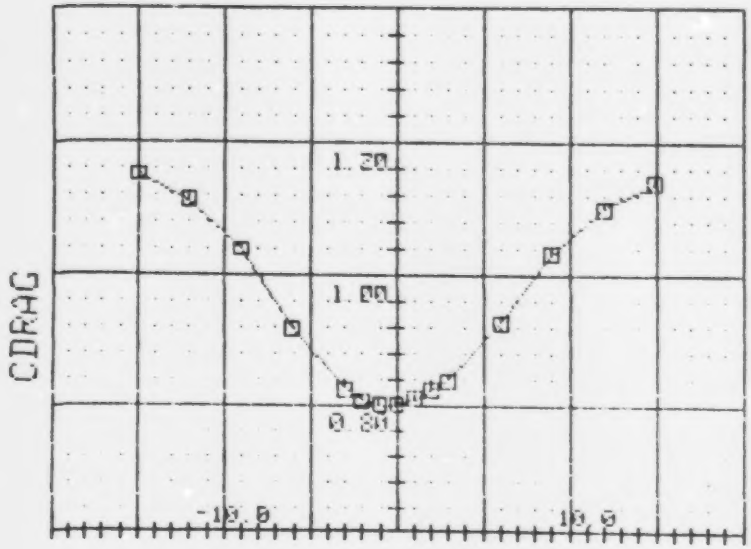
Velocity= 237.1 ft/sec Re= 1.210

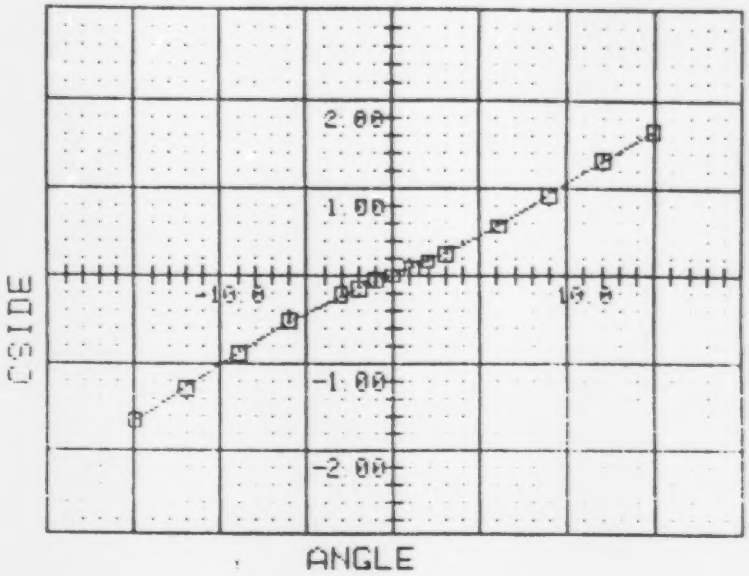
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-14.99	-2.832	1.835	-1.666	5.265	-0.725	1.150	1.11
-12.02	-2.063	1.443	-1.288	4.607	-0.535	1.112	1.10
-8.98	-1.342	1.033	-0.885	3.870	-0.383	1.039	1.08
-6.03	-0.739	0.591	-0.531	3.037	-0.228	0.918	1.07
-3.02	-0.313	0.231	-0.233	2.395	-0.117	0.823	1.06
-2.00	-0.200	0.162	-0.149	2.272	-0.100	0.805	1.06
-1.01	-0.096	0.119	-0.071	2.236	-0.090	0.800	1.06
-0.03	0.001	-0.008	-0.012	2.242	-0.103	0.800	1.06
1.03	0.112	-0.050	0.074	2.286	-0.109	0.808	1.06
1.97	0.212	-0.082	0.154	2.363	-0.119	0.821	1.06
2.98	0.318	-0.142	0.241	2.483	-0.136	0.837	1.06
6.05	0.780	-0.478	0.558	3.118	-0.254	0.925	1.07
8.99	1.366	-0.970	0.912	3.887	-0.368	1.031	1.08
12.02	2.081	-1.365	1.306	4.604	-0.519	1.100	1.10
14.93	2.782	-1.770	1.651	5.213	-0.681	1.139	1.11

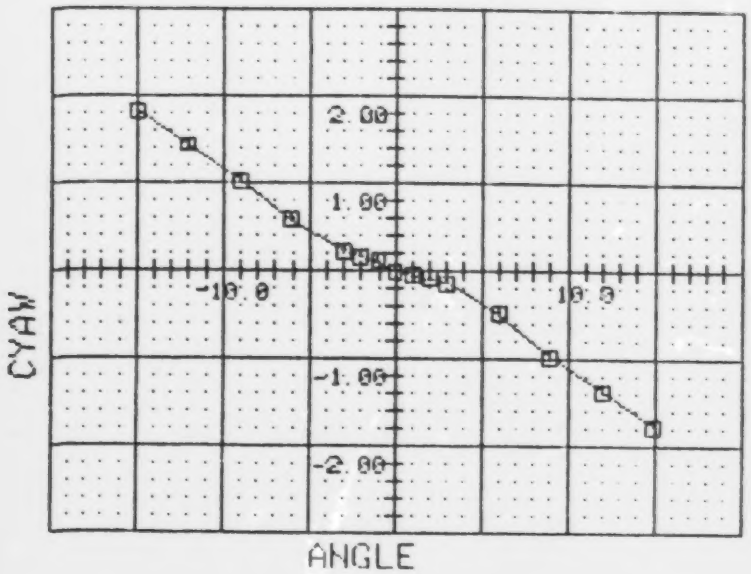
Wind Averaged Drag Coefficient at 55. mph = 0.902

Run 3

ASTRO 95, FRONT 1B







B15

RUN NUMBER 4 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 1A + 1B

18-MAR-83 09:49:18 Tare No 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

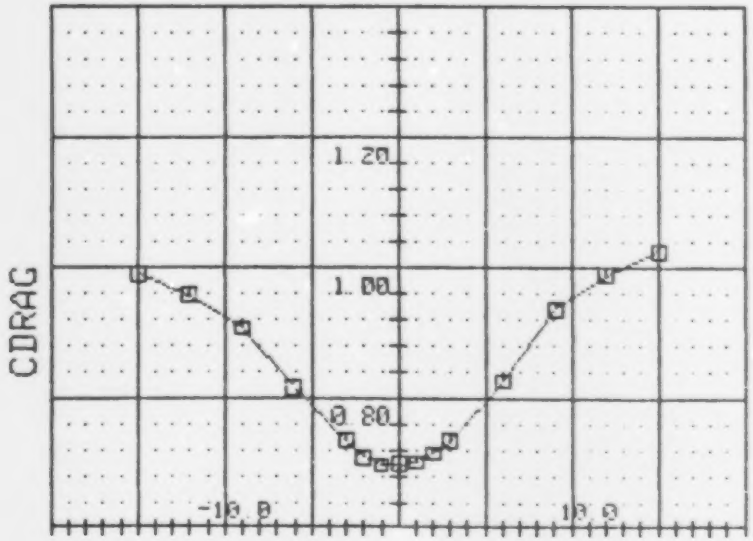
Velocity= 236.2 ft/sec Re= 1 206

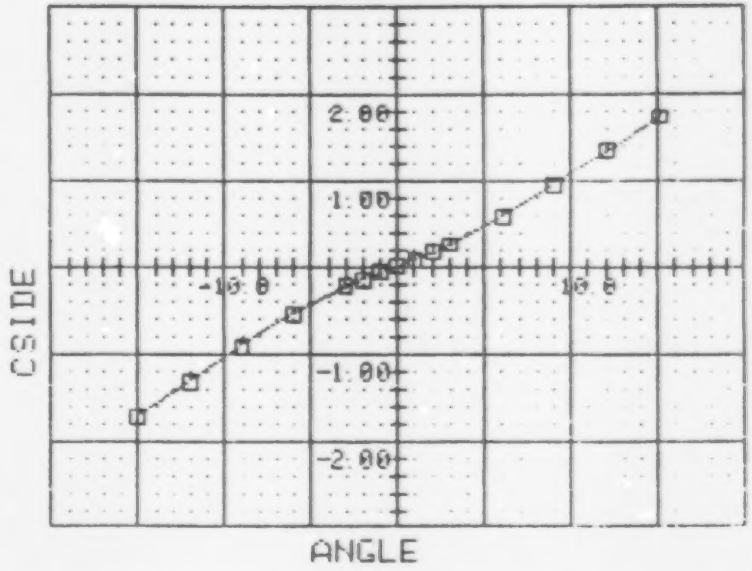
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15 03	-2.839	1.708	-1.728	4 889	-0.732	0.988	1.10
-12 03	-2.054	1 369	-1.329	4.202	-0 522	0.956	1.09
-9 02	-1.343	0.978	-0.921	3 499	-0 336	0 905	1.07
-6.05	-0.750	0.573	-0.554	2.749	-0.198	0.815	1.06
-3 03	-0 319	0.265	-0.238	2 197	-0 086	0.733	1.05
-2.00	-0.203	0 144	-0.152	2 064	-0 081	0.707	1.05
-1 00	-0.093	0 093	-0.069	2.012	-0 072	0.696	1.05
0 01	0 005	-0 009	-0.005	2.031	-0.085	0.696	1.05
1 00	0.109	-0.027	0.079	2.037	-0 087	0.700	1.05
2 01	0 211	-0 065	0.162	2.112	-0 096	0.714	1.05
3 00	0 319	-0 122	0.255	2 225	-0 113	0 733	1.05
6 06	0 791	-0 452	0.577	2.863	-0 227	0 824	1.06
9 03	1.389	-0 978	0.943	3.644	-0.332	0 935	1.08
12 02	2.102	-1.383	1.342	4 334	-0.503	0.986	1.09
15 09	2 871	-1.769	1 725	5 006	-0 708	1 024	1 10

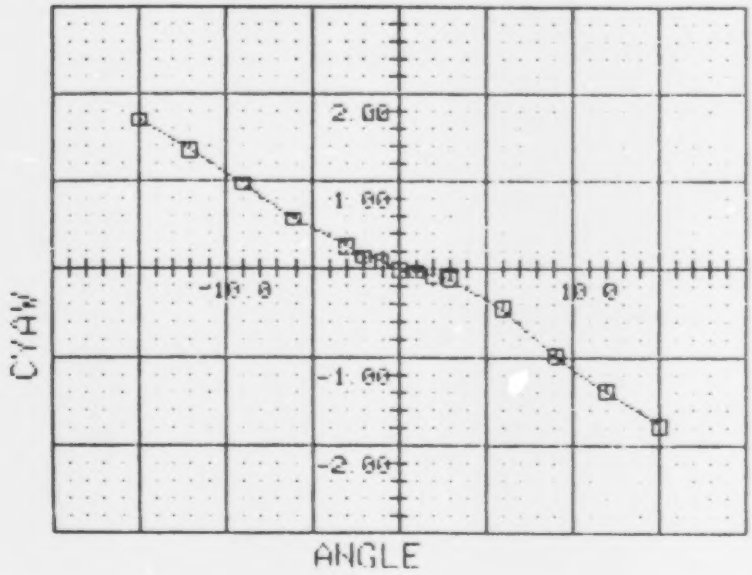
Wind Averaged Drag Coefficient at 55 mph = 0.797

Run 4

ASTRO 95, FRONT 1H + 1B







B17

RUN NUMBER 5 REPORT NUMBER 389

LES PNEUS METRIC

ASTRO 95, FRONT 1A

18-MAR-83 10:07:38 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

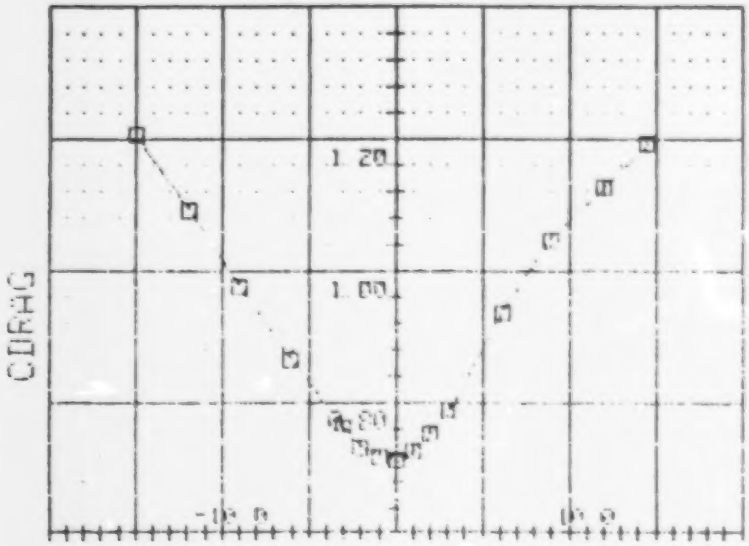
Velocity= 237.7 ft/sec Re= 1.214

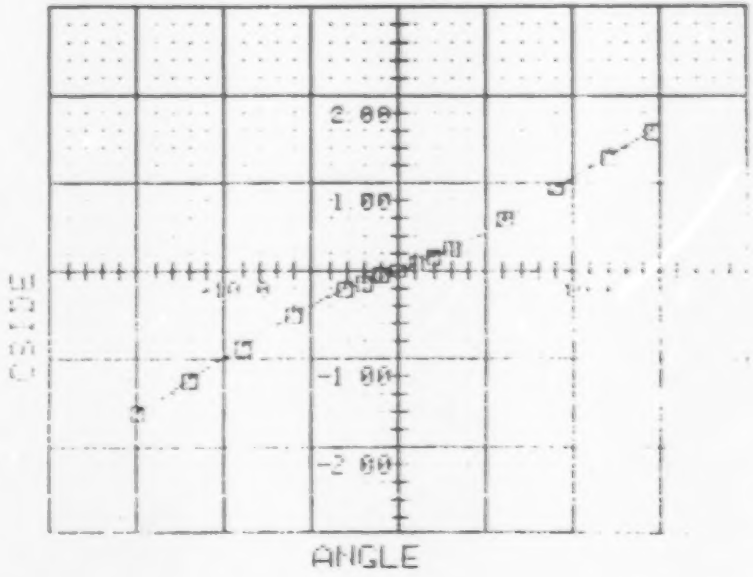
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-14.98	-2.843	2.458	-1.618	5.329	-0.598	1.204	1.12
-11.95	-2.038	1.805	-1.254	4.509	-0.489	1.090	1.10
-8.98	-1.350	1.255	-0.889	3.712	-0.343	0.976	1.08
-6.05	-0.741	0.733	-0.524	2.917	-0.229	0.863	1.06
-3.05	-0.304	0.375	-0.224	2.224	-0.108	0.762	1.05
-2.00	-0.193	0.215	-0.148	2.081	-0.105	0.731	1.05
-0.98	-0.090	0.114	-0.068	2.035	-0.103	0.717	1.05
0.01	0.004	-0.066	-0.007	2.034	-0.112	0.711	1.05
1.00	0.099	-0.154	0.062	2.087	-0.109	0.723	1.05
1.97	0.199	-0.276	0.142	2.197	-0.114	0.750	1.05
3.03	0.311	-0.415	0.227	2.391	-0.128	0.787	1.06
6.12	0.825	-1.018	0.568	3.220	-0.204	0.935	1.07
8.99	1.397	-1.476	0.922	3.921	-0.306	1.047	1.08
11.98	2.083	-1.900	1.285	4.596	-0.427	1.125	1.10
14.52	2.718	-2.356	1.585	5.169	-0.536	1.191	1.11

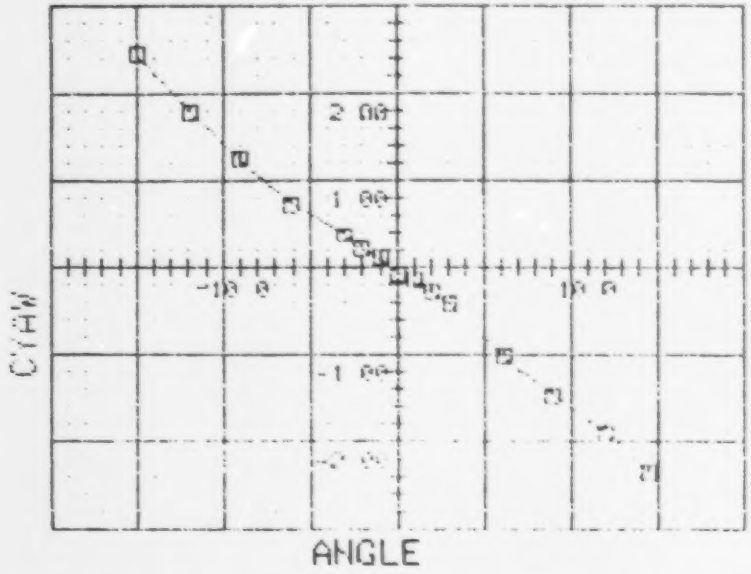
Wind Averaged Drag Coefficient at 55. mph = 0.857

Run 5

ASTRO 95, FRONT 1A







B19

RUN NUMBER 6 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 3

18-MAR-83 10:38:27 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

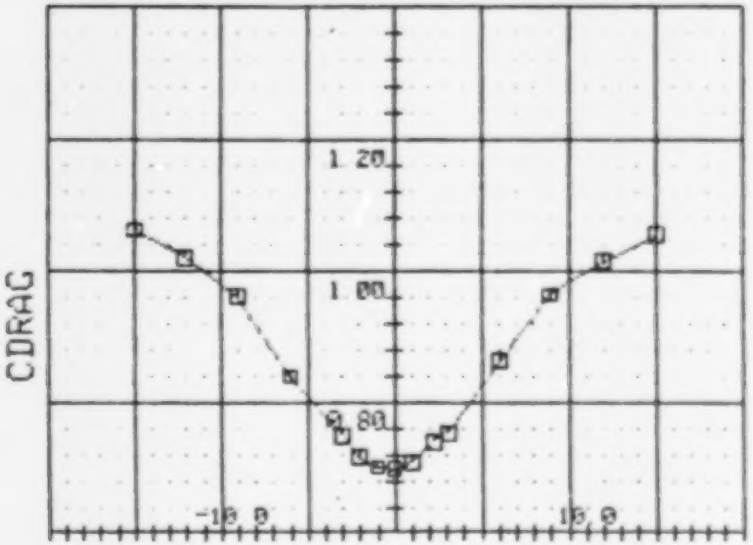
Velocity= 237.0 ft/sec Re= 1.210

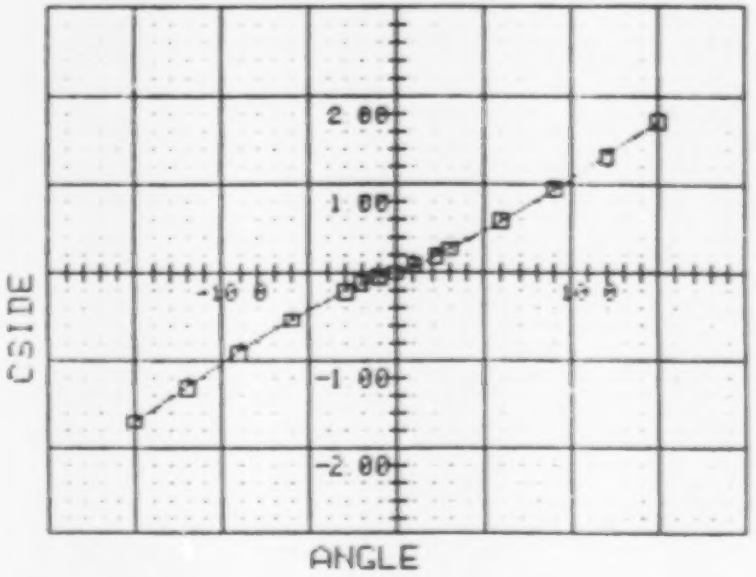
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.03	-2.915	1.894	-1.712	5.121	-0.706	1.061	1.11
-12.04	-2.131	1.507	-1.329	4.455	-0.503	1.020	1.09
-9.03	-1.425	1.137	-0.928	3.776	-0.311	0.961	1.08
-6.02	-0.768	0.630	-0.544	2.919	-0.164	0.838	1.06
-2.97	-0.311	0.327	-0.218	2.321	-0.065	0.748	1.05
-2.04	-0.198	0.234	-0.139	2.180	-0.050	0.715	1.05
-1.01	-0.088	0.143	-0.058	2.098	-0.043	0.700	1.05
-0.02	0.005	-0.033	-0.007	2.088	-0.062	0.697	1.05
1.02	0.109	-0.093	0.071	2.151	-0.064	0.708	1.05
2.27	0.245	-0.142	0.178	2.279	-0.083	0.739	1.05
3.06	0.340	-0.152	0.257	2.372	-0.097	0.752	1.05
5.98	0.811	-0.616	0.561	3.078	-0.171	0.862	1.06
8.98	1.422	-1.088	0.938	3.803	-0.288	0.963	1.08
11.98	2.111	-1.419	1.320	4.424	-0.468	1.014	1.09
15.02	2.872	-1.801	1.698	5.073	-0.663	1.054	1.11

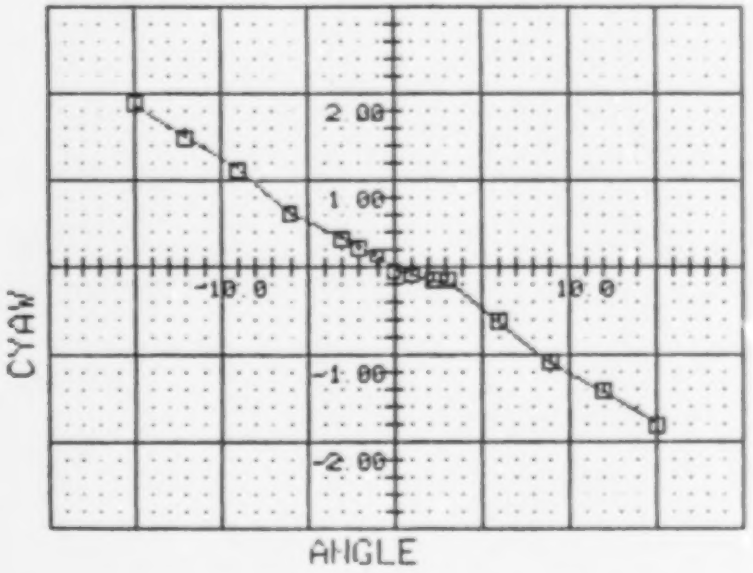
Wind Averaged Drag Coefficient at 55. mph = 0.822

Run 6

ASTRO 25. FRONT 3







921

RUN NUMBER 7 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 3, REAR 5

18-MAR-83 10:54:39 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

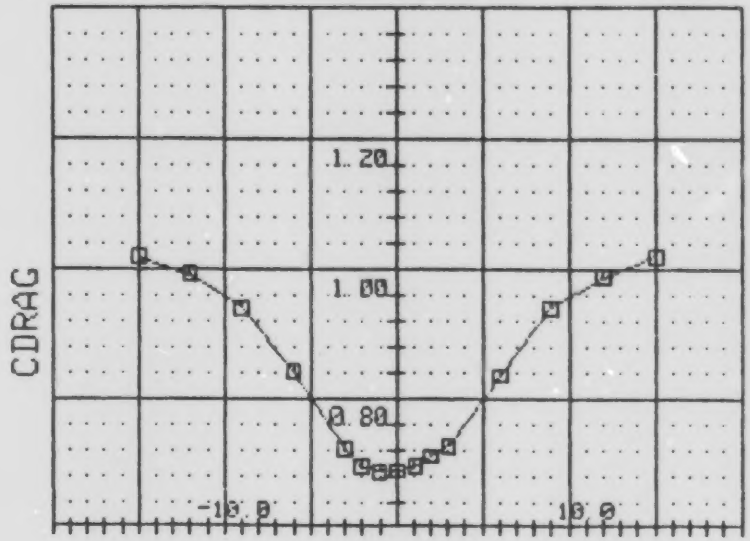
Velocity= 236.4 ft/sec Re= 1.207

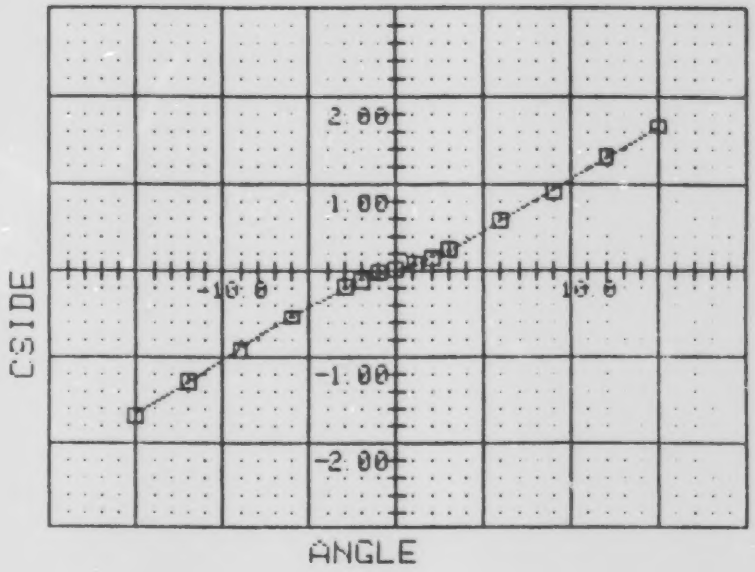
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.02	-2.906	1:839	-1.691	5.086	-0.738	1.018	1.10
-12.00	-2.135	1.470	-1.306	4.498	-0.544	0.991	1.09
-9.01	-1.442	1.153	-0.925	3.827	-0.350	0.940	1.08
-6.00	-0.791	0.670	-0.541	3.022	-0.213	0.840	1.06
-2.97	-0.297	0.293	-0.206	2.201	-0 062	0.721	1.05
-2.00	-0.178	0.185	-0.121	2.088	-0.054	0.692	1.05
-1.00	-0.063	0.048	-0.034	2.088	-0.063	0.685	1.05
0.01	0.006	-0.057	-0.003	2.088	-0.077	0.686	1.05
1.07	0.102	-0.075	0.065	2.116	-0.074	0.693	1.05
2.00	0.201	-0.121	0.143	2.187	-0.081	0.709	1.05
3.04	0.316	-0.116	0.239	2.294	-0.108	0.725	1.05
5.98	0.823	-0.560	0.570	3.116	-0.223	0.834	1.06
8.98	1.414	-1.053	0.916	3.829	-0.316	0.939	1.08
12.01	2.114	-1.350	1.300	4.464	-0.509	0.987	1.09
15 02	2.826	-1.683	1.659	5.033	-0.692	1.019	1.10

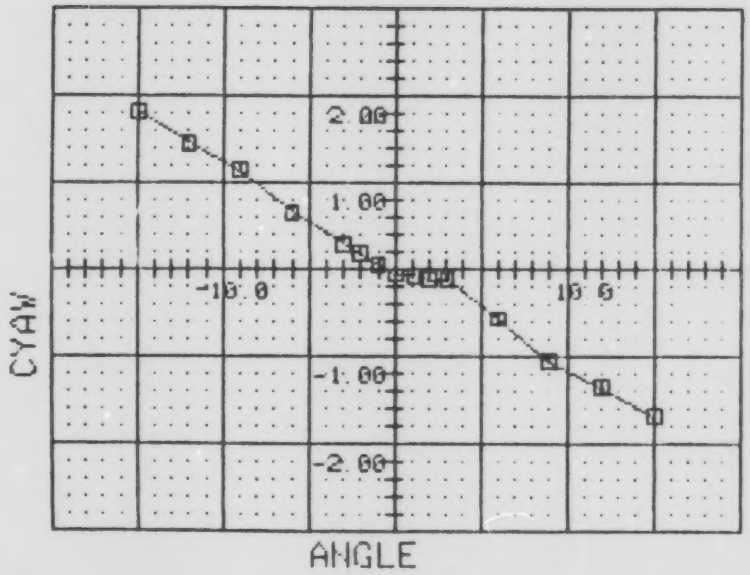
Wind Averaged Drag Coefficient at 55. mph = 0.804

Run 7

ASTRO 95, FRONT 3, REAR 5







RUN NUMBER 8 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 3, REAR 7

18-MAR-83 11:11:04 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

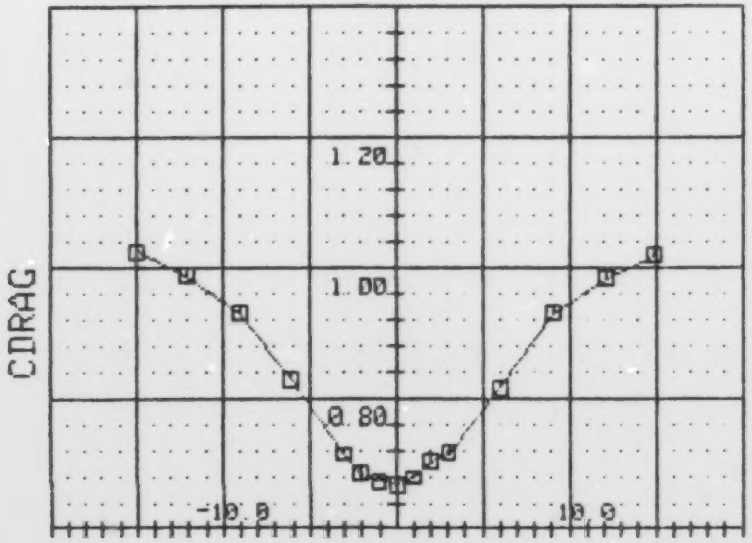
Velocity= 236.6 ft/sec Re= 1.208

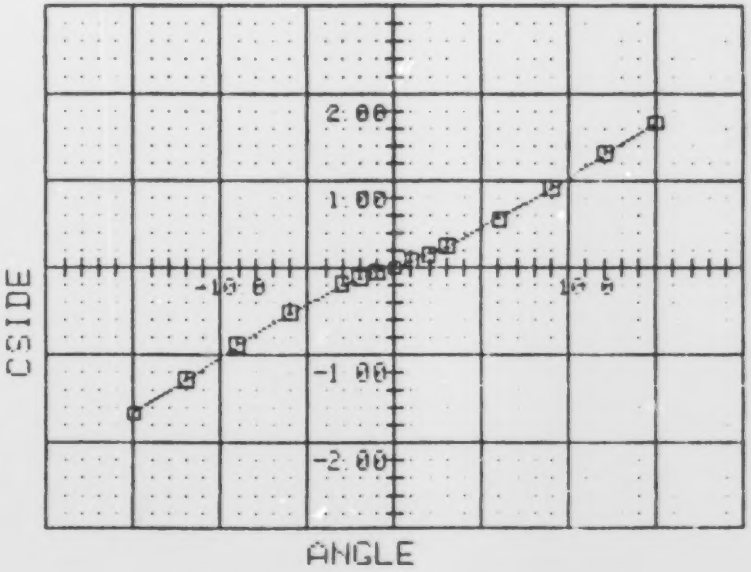
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-14.99	-2.860	1.787	-1.679	5.000	-0.702	1.024	1.10
-12.03	-2.085	1.419	-1.299	4.342	-0.498	0.987	1.09
-9.03	-1.389	1.045	-0.901	3.679	-0.311	0.929	1.07
-6.04	-0.772	0.599	-0.532	2.924	-0.184	0.828	1.06
-3.02	-0.299	0.260	-0.203	2.233	-0.066	0.713	1.05
-2.03	-0.190	0.188	-0.129	2.085	-0.052	0.683	1.05
-1.01	-0.084	0.125	-0.051	2.010	-0.040	0.672	1.05
0.03	0.000	-0.031	-0.007	1.998	-0.061	0.668	1.05
0.99	0.097	-0.076	0.065	2.052	-0.061	0.678	1.05
1.99	0.203	-0.117	0.149	2.165	-0.073	0.701	1.05
3.03	0.313	-0.119	0.238	2.279	-0.099	0.715	1.05
6.00	0.778	-0.449	0.547	2.952	-0.190	0.814	1.06
9.03	1.373	-0.972	0.905	3.683	-0.283	0.929	1.07
12.09	2.085	-1.315	1.304	4.355	-0.481	0.982	1.09
14.97	2.800	-1.689	1.661	4.960	-0.663	1.018	1.10

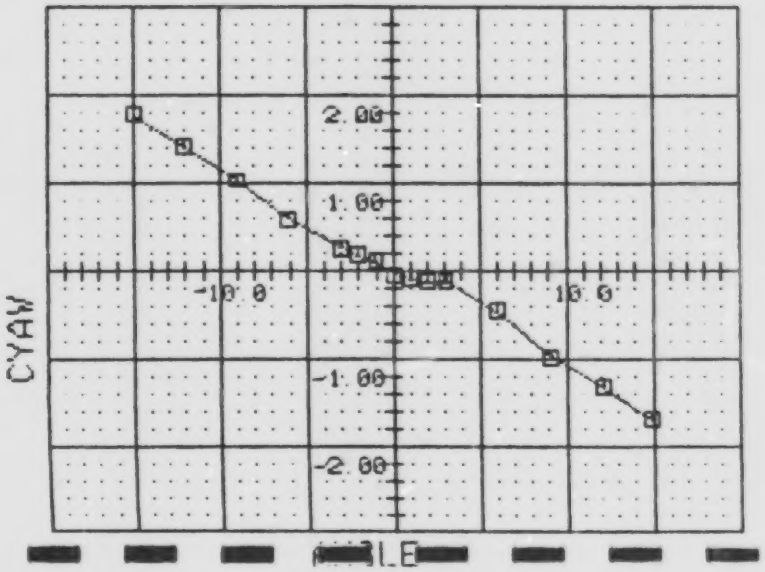
Wind Averaged Drag Coefficient at 55. mph = 0.790

Run 8

ASTRO 95, FRONT 3, REAR 7







RUN NUMBER 9 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 3, REAR 6

18-MAR-83 11:28:32 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

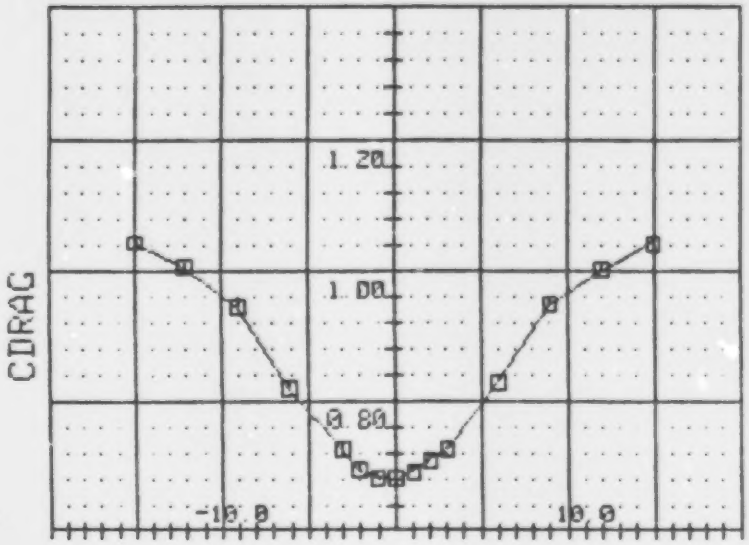
Velocity= 236.6 ft/sec Re= 1.208

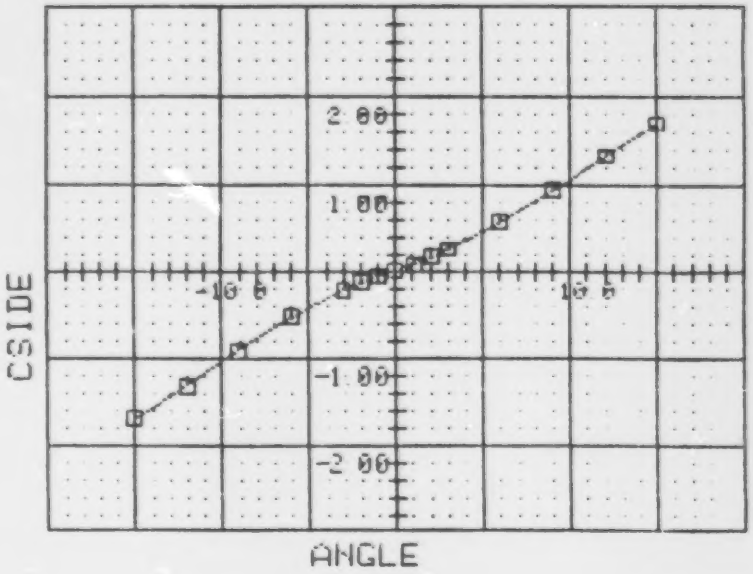
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.03	-2.909	1.874	-1.706	5.085	-0.707	1.043	1.10
-12.04	-2.126	1.490	-1.323	4.417	-0.504	1.005	1.09
-9.03	-1.418	1.111	-0.926	3.713	-0.309	0.943	1.08
-6.05	-0.762	0.606	-0.540	2.849	-0.156	0.818	1.06
-3.02	-0.315	0.315	-0.220	2.232	-0.057	0.725	1.05
-2.00	-0.195	0.230	-0.136	2.055	-0.036	0.693	1.05
-1.02	-0.088	0.144	-0.056	1.975	-0.024	0.681	1.05
0.00	0.004	-0.040	-0.001	1.979	-0.046	0.679	1.05
1.07	0.107	-0.106	0.078	2.041	-0.053	0.689	1.05
2.05	0.213	-0.170	0.162	2.143	-0.063	0.708	1.05
3.03	0.323	-0.161	0.253	2.262	-0.086	0.726	1.05
5.98	0.798	-0.516	0.567	2.986	-0.184	0.828	1.06
9.00	1.415	-1.082	0.936	3.771	-0.285	0.947	1.08
12.05	2.127	-1.437	1.329	4.437	-0.485	1.000	1.09
14.98	2.859	-1.809	1.691	5.073	-0.669	1.042	1.10

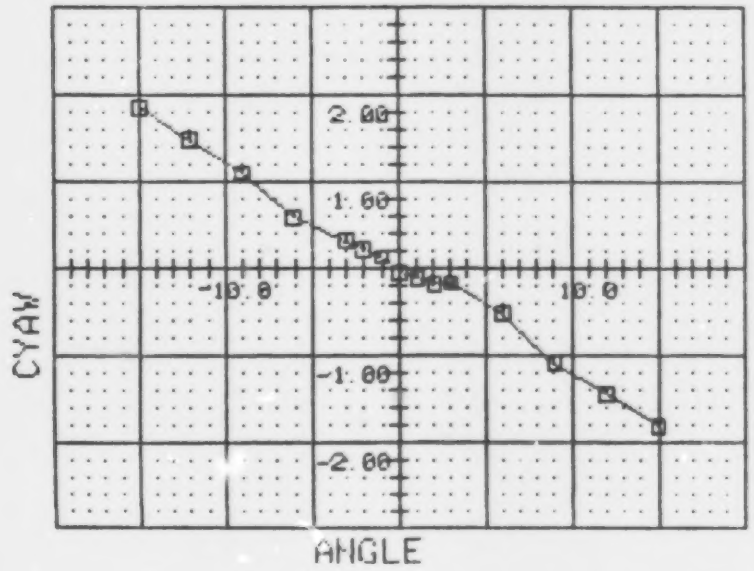
Wind Averaged Drag Coefficient at 55. mph = 0.797

Run 9

ASTRO 95, FRONT 3, REAR 6







827

RUN NUMBER 10 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 3, REAR 8

18-MAR-83 11:43:28 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

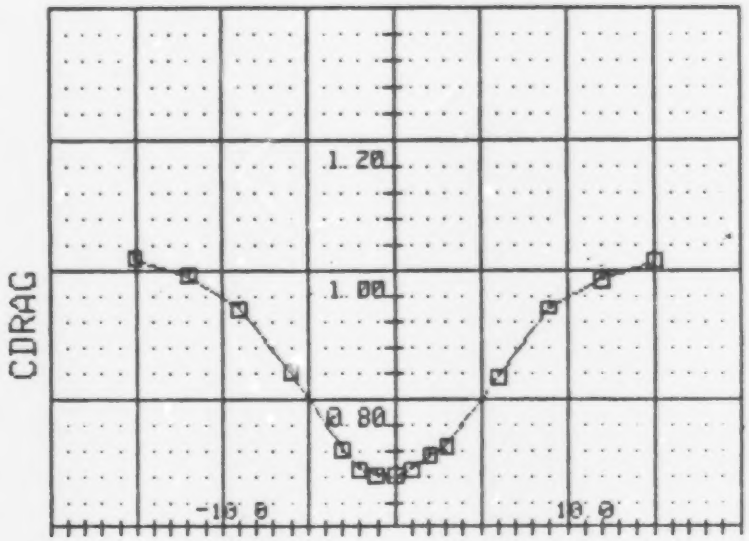
Velocity= 236.6 ft/sec Re= 1.208

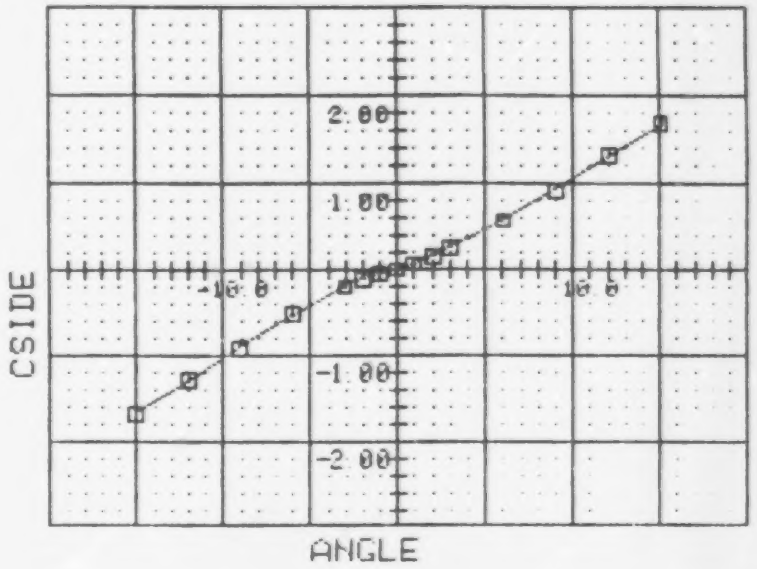
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.06	-2.999	1.830	-1.690	5.276	-0.774	1.019	1.10
-11.95	-2.184	1.465	-1.299	4.658	-0.573	0.991	1.09
-9.03	-1.482	1.113	-0.918	4.000	-0.381	0.940	1.08
-6.00	-0.808	0.632	-0.530	3.166	-0.241	0.839	1.06
-3.04	-0.318	0.295	-0.207	2.390	-0.099	0.720	1.05
-2.00	-0.191	0.192	-0.122	2.224	-0.074	0.689	1.05
-1.03	-0.092	0.110	-0.052	2.195	-0.074	0.680	1.05
0.00	-0.006	-0.026	-0.010	2.234	-0.103	0.680	1.05
0.98	0.094	-0.056	0.060	2.272	-0.102	0.690	1.05
2.05	0.213	-0.119	0.147	2.365	-0.115	0.710	1.05
3.02	0.334	-0.130	0.245	2.478	-0.144	0.726	1.05
6.00	0.832	-0.511	0.558	3.254	-0.255	0.832	1.06
8.99	1.460	-1.039	0.917	4.000	-0.351	0.941	1.08
12.02	2.176	-1.369	1.301	4.630	-0.539	0.984	1.09
15.07	2.938	-1.724	1.672	5.223	-0.729	1.013	1.10

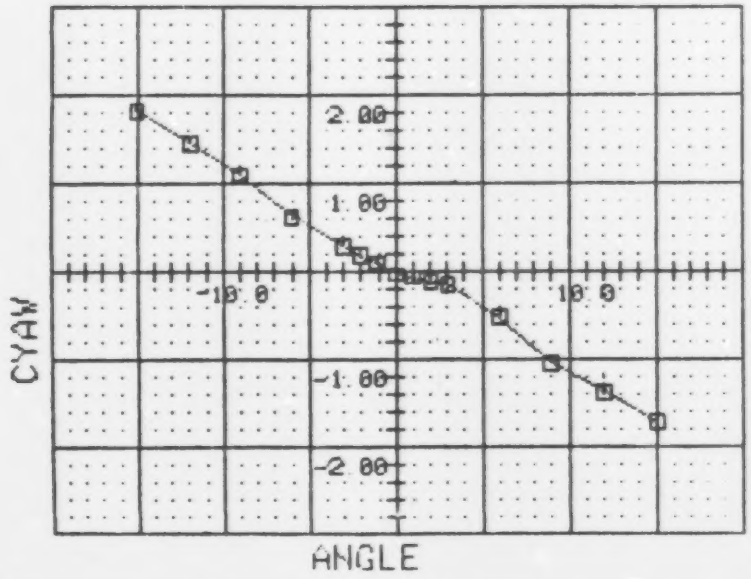
Wind Averaged Drag Coefficient at 55. mph = 0.803

Run 10

ASTRO 95, FRONT 3, REAR 8







B29

RUN NUMBER 11 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO, FRONT 3, REAR 4

18-MAR-83 11:55:11 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

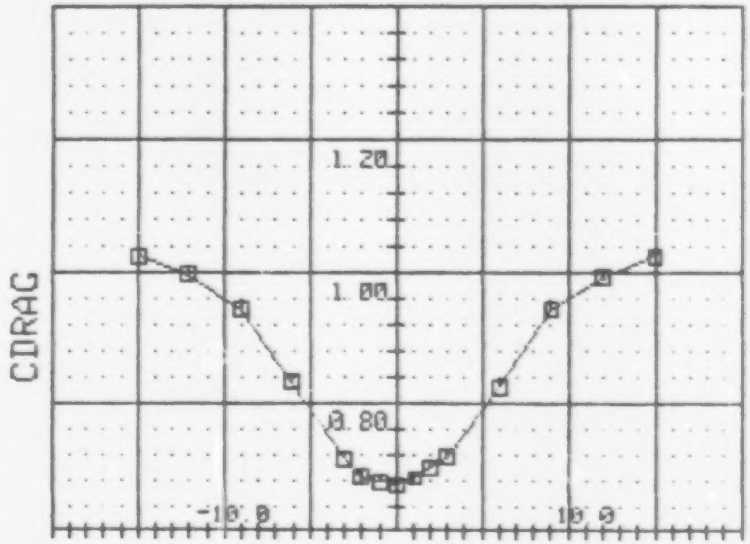
Velocity= 236.3 ft/sec Re= 1.206

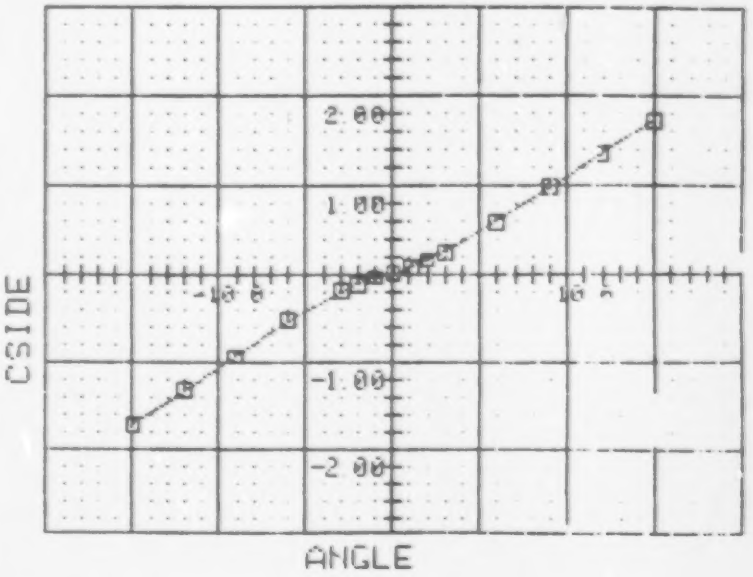
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-14.98	-2.898	1.955	-1.719	5.010	-0.705	1.024	1.10
-12.03	-2.137	1.576	-1.331	4.414	-0.512	0.995	1.09
-9.03	-1.445	1.221	-0.944	3.757	-0.324	0.941	1.08
-6.04	-0.771	0.643	-0.536	2.917	-0.182	0.831	1.06
-2.97	-0.278	0.249	-0.195	2.121	-0.049	0.712	1.05
-2.00	-0.171	0.162	-0.118	1.978	-0.035	0.683	1.05
-0.97	-0.073	0.089	-0.042	1.989	-0.043	0.677	1.05
0.05	0.011	-0.061	0.001	1.973	-0.058	0.673	1.05
1.07	0.110	-0.110	0.076	2.006	-0.052	0.682	1.05
1.97	0.205	-0.169	0.156	2.074	-0.057	0.699	1.05
2.99	0.316	-0.167	0.250	2.167	-0.078	0.716	1.05
5.97	0 814	-0.611	0.581	2 968	-0.184	0.824	1.06
9.00	1.448	-1.213	0 966	3.772	-0.294	0.942	1.08
12 00	2.148	-1.566	1.355	4 410	-0.483	0.992	1.09
14.98	2.855	-1.890	1.714	4.977	-0.661	1.024	1.10

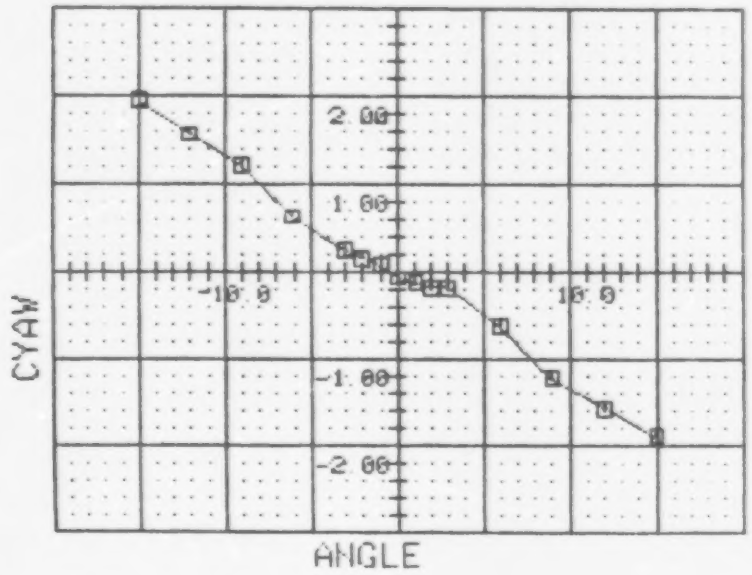
Wind Averaged Drag Coefficient at 55. mph = 0.796

Run 11

ASTRO, FRONT 3, REAR 4







B31

RUN NUMBER 12 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 3, DEFLECTOR

18-MAR-83 12:10:05 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

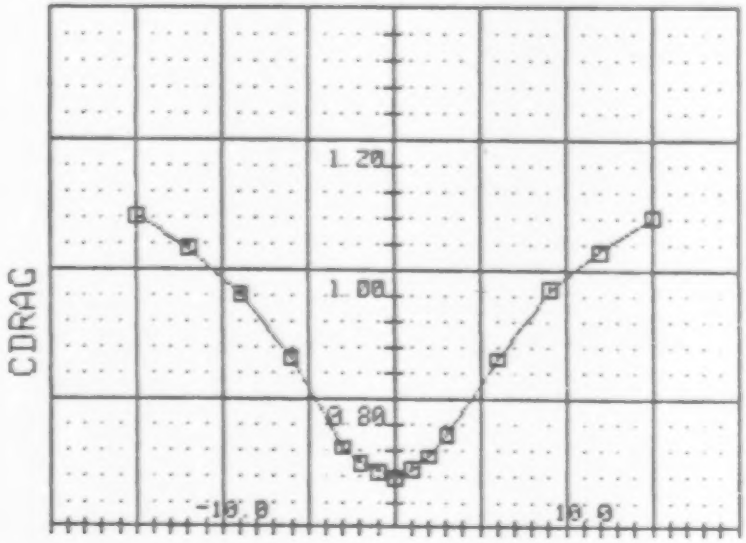
Velocity= 237.1 ft/sec Re= 1.210

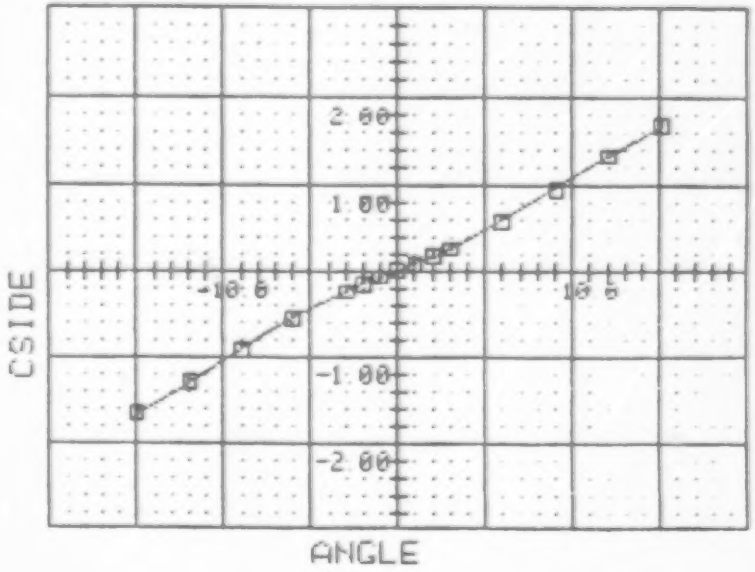
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-14.97	-2.932	2.029	-1.668	5.144	-0.537	1.082	1.11
-11.94	-2.168	1.639	-1.303	4.520	-0.361	1.032	1.09
-8.93	-1.457	1.228	-0.920	3.876	-0.215	0.960	1.08
-6.00	-0.836	0.786	-0.552	3.175	-0.089	0.861	1.06
-2.98	-0.353	0.286	-0.241	2.443	-0.024	0.723	1.05
-1.99	-0.225	0.184	-0.157	2.324	-0.004	0.698	1.05
-0.98	-0.113	0.104	-0.080	2.268	0.007	0.685	1.05
0.01	0.011	-0.024	0.002	2.237	0.004	0.676	1.05
1.00	0.124	-0.091	0.082	2.295	0.002	0.688	1.05
2.03	0.241	-0.174	0.165	2.407	-0.007	0.709	1.05
3.03	0.368	-0.295	0.256	2.586	-0.024	0.743	1.05
5.97	0.867	-0.720	0.582	3.227	-0.091	0.861	1.06
9.06	1.496	-1.203	0.951	3.935	-0.185	0.969	1.08
12.02	2.194	-1.544	1.323	4.532	-0.318	1.028	1.09
15.11	2.924	-1.894	1.674	5.156	-0.494	1.080	1.11

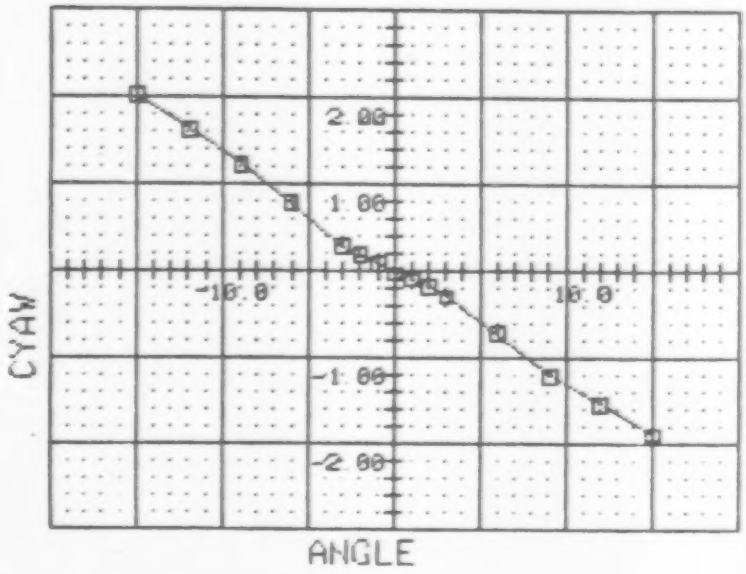
Wind Averaged Drag Coefficient at 55 mph = 0.820

Run 12

ASTRO 95, FRONT 3, DEFLECTOR







B33

RUN NUMBER 13 REPORT NUMBER 388

LES PNEUS MICHELIN MXTRIX

ASTRO 95, DEFLECTOR

18-MAR-83 12:25:17 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

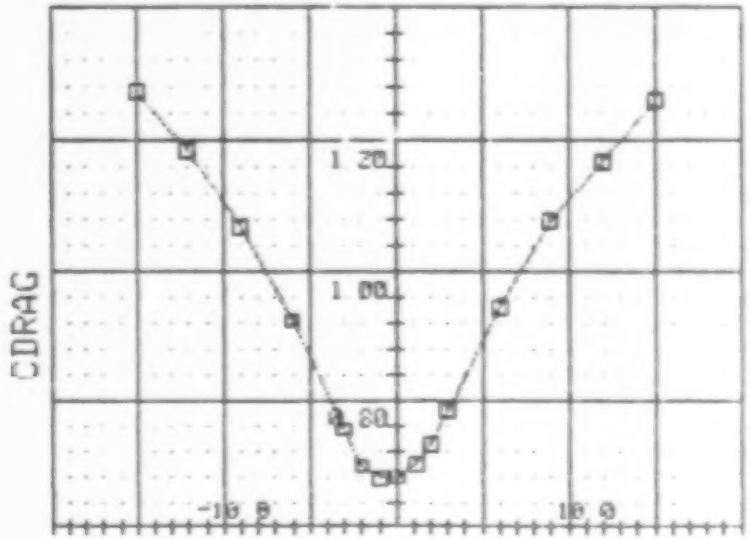
Velocity= 238.5 ft/sec Re= 1.218

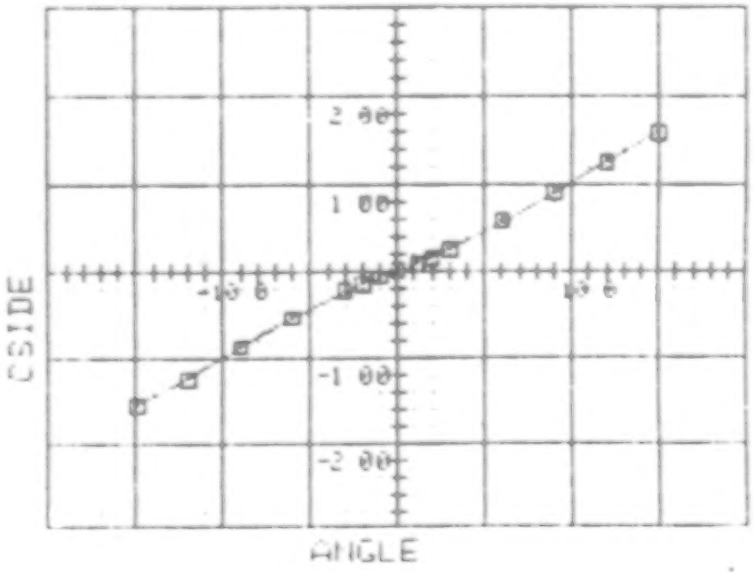
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-14.93	-2.831	2.527	-1.559	5.467	-0.465	1.272	1.12
-12.03	-2.139	2.096	-1.250	4.855	-0.339	1.185	1.10
-9.01	-1.467	1.688	-0.882	4.162	-0.231	1.069	1.08
-6.00	-0.851	1.069	-0.546	3.418	-0.143	0.923	1.07
-3.01	-0.363	0.433	-0.241	2.598	-0.081	0.753	1.05
-1.99	-0.218	0.214	-0.153	2.346	-0.068	0.696	1.05
-0.97	-0.100	0.080	-0.075	2.271	-0.058	0.677	1.05
0.05	0.012	-0.058	-0.001	2.279	-0.054	0.678	1.05
1.13	0.136	-0.200	0.082	2.374	-0.057	0.698	1.05
1.97	0.239	-0.322	0.152	2.514	-0.066	0.730	1.05
2.99	0.373	-0.487	0.248	2.741	-0.078	0.782	1.05
6.02	0.887	-1.121	0.571	3.519	-0.121	0.943	1.07
8.99	1.478	-1.595	0.904	4.221	-0.214	1.076	1.09
12.00	2.137	-2.025	1.252	4.825	-0.306	1.167	1.10
15.01	2.853	-2.447	1.579	5.433	-0.428	1.258	1.12

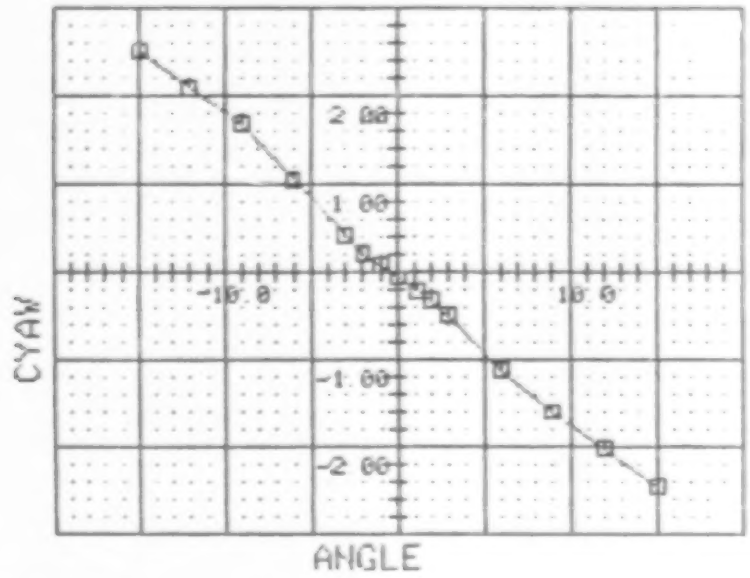
Wind Averaged Drag Coefficient at 55. mph = 0.873

Run 13

ASTRO 95. DEFLECTOR







RUN NUMBER 14 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, 1B(MOD) ON TRACTOR + DEFLECTOR

18-MAR-83 13:11:41 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

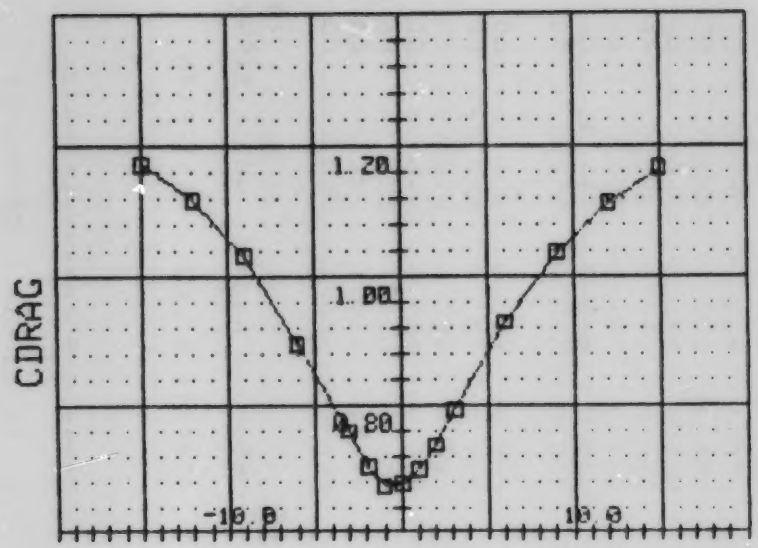
Velocity= 755.6 ft/sec Re= 3.858

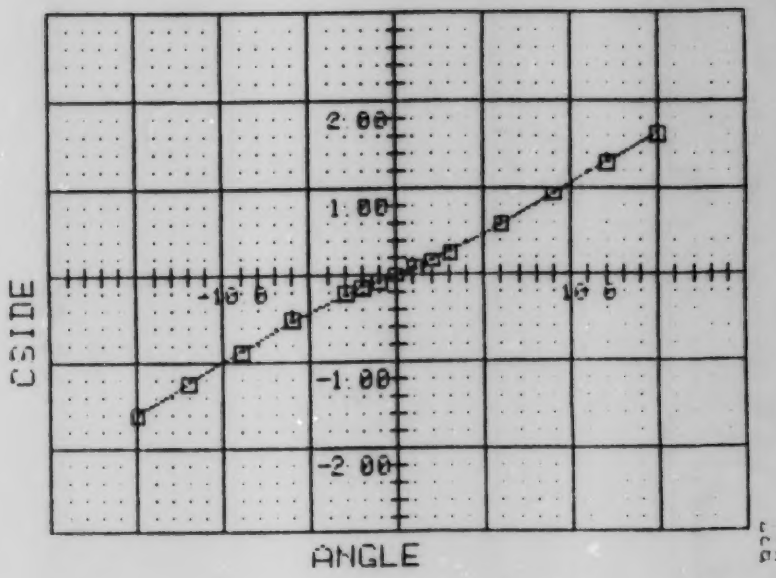
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-14.98	-2.816	2.194	-1.619	5.227	-0.530	1.172	1.11
-12.00	-2.107	1.806	-1.261	4.658	-0.395	1.118	1.10
-8.98	-1.435	1.516	-0.895	3.964	-0.234	1.032	1.08
-6.00	-0.808	0.898	-0.533	3.147	-0.123	0.892	1.07
-3.00	-0.362	0.490	-0.238	2.535	-0.037	0.758	1.05
-1.95	-0.228	0.277	-0.157	2.303	-0.019	0.702	1.05
-1.00	-0.108	0.048	-0.081	2.199	-0.022	0.673	1.05
0.00	0.003	-0.120	-0.010	2.213	-0.021	0.674	1.05
1.03	0.122	-0.262	0.070	2.302	-0.017	0.698	1.05
2.02	0.245	-0.387	0.156	2.458	-0.031	0.735	1.05
3.09	0.378	-0.565	0.250	2.677	-0.050	0.792	1.06
6.00	0.856	-1.040	0.564	3.342	-0.105	0.928	1.07
9.03	1.446	-1.421	0.925	4.039	-0.226	1.035	1.08
12.07	2.114	-1.709	1.281	4.644	-0.340	1.111	1.10
15.00	2.778	-2.105	1.618	5.214	-0.493	1.164	1.11

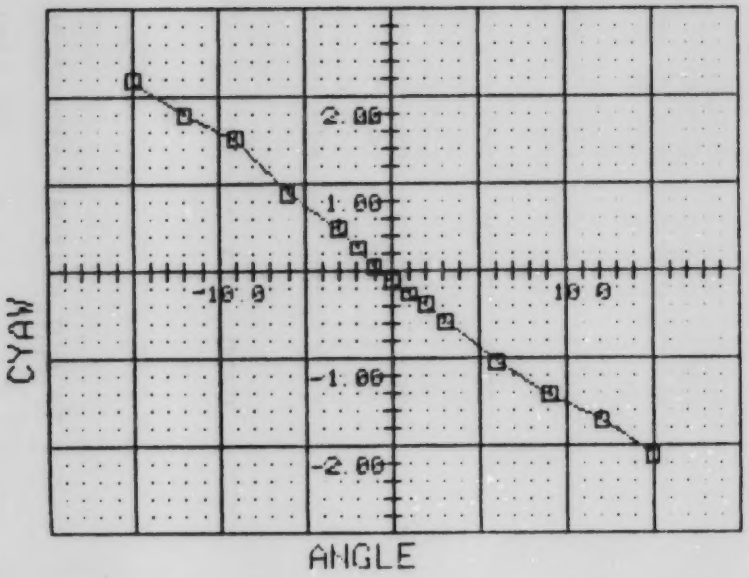
Wind Averaged Drag Coefficient at 55. mph = 0.859

Run 14

ASTRO 95, 1B(MOD) ON TRACTOR + DEFLECTOR







RUN NUMBER 15 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 2 AND DEFLECTOR

18-MAR-83 13:32:31 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

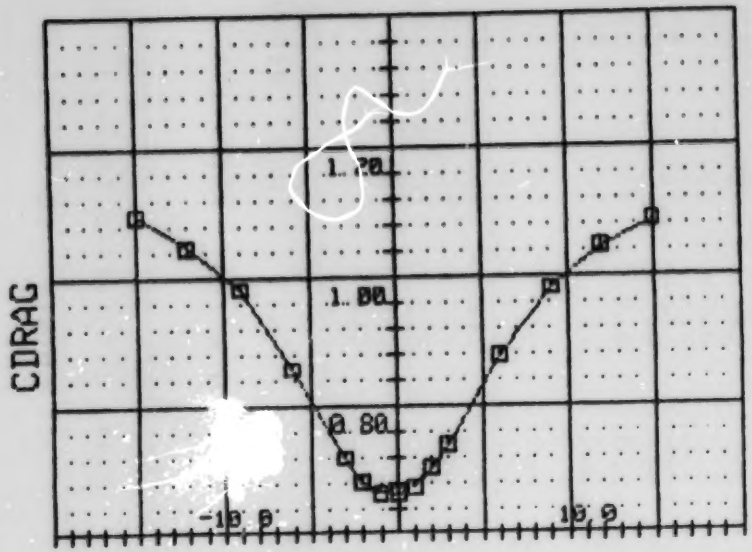
Velocity= 237.4 ft/sec Re= 1.212

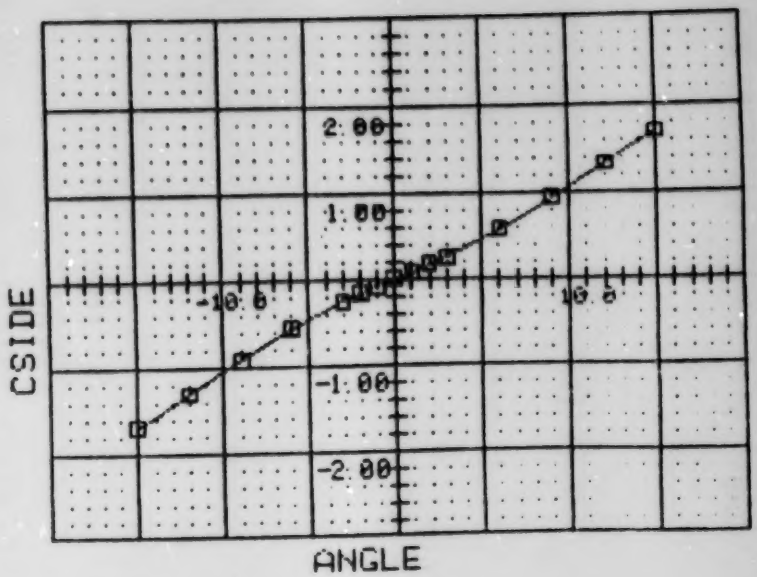
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.03	-2.890	1.931	-1.703	5.139	-0.614	1.095	1.11
-12.03	-2.122	1.594	-1.314	4.470	-0.415	1.046	1.09
-8.98	-1.432	1.240	-0.916	3.849	-0.258	0.981	1.08
-6.05	-0.816	0.634	-0.564	3.101	-0.160	0.856	1.06
-3.02	-0.350	0.236	-0.249	2.412	-0.053	0.718	1.05
-2.00	-0.223	0.121	-0.164	2.246	-0.039	0.679	1.05
-1.02	-0.108	0.057	-0.082	2.183	-0.024	0.663	1.05
0.01	0.004	-0.009	-0.002	2.187	-0.025	0.661	1.05
1.00	0.111	-0.079	0.072	2.246	-0.029	0.672	1.05
1.99	0.231	-0.168	0.160	2.367	-0.043	0.701	1.05
2.99	0.348	-0.266	0.249	2.521	-0.058	0.738	1.05
6.02	0.842	-0.774	0.573	3.197	-0.114	0.876	1.06
9.03	1.442	-1.203	0.939	3.891	-0.238	0.980	1.08
12.02	2.140	-1.554	1.329	4.515	-0.378	1.045	1.09
15.00	2.841	-1.855	1.697	5.091	-0.559	1.085	1.11

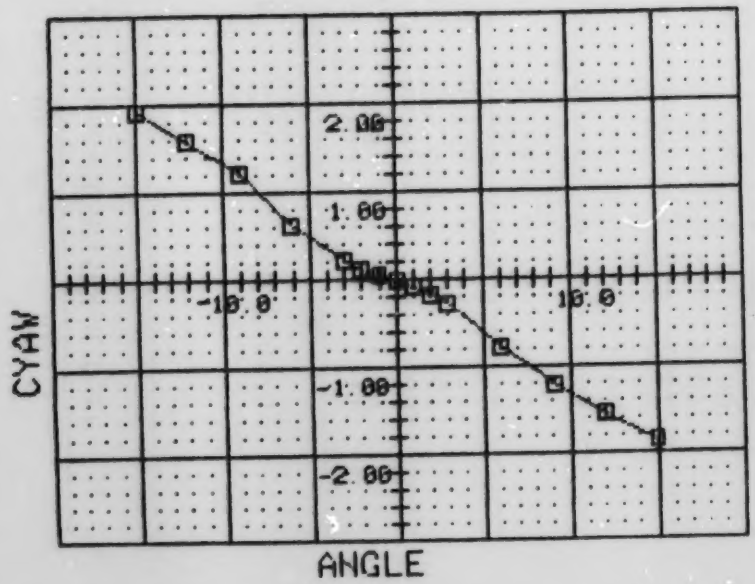
Wind Averaged Drag Coefficient at 55. mph = 0.818

Run 15

ASTRO 95, FRONT 2 AND DEFLECTOR







B39

RUN NUMBER 16 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 2

18-MAR-83 13:43:17 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

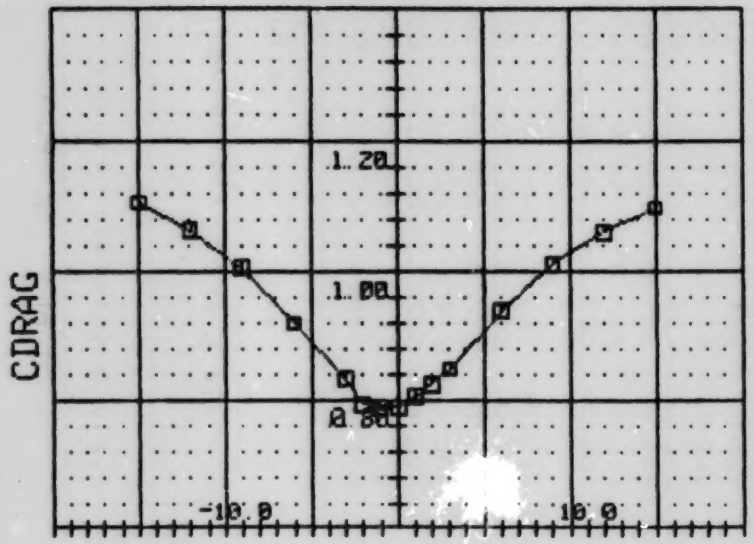
Velocity= 237.9 ft/sec Re= 1.214

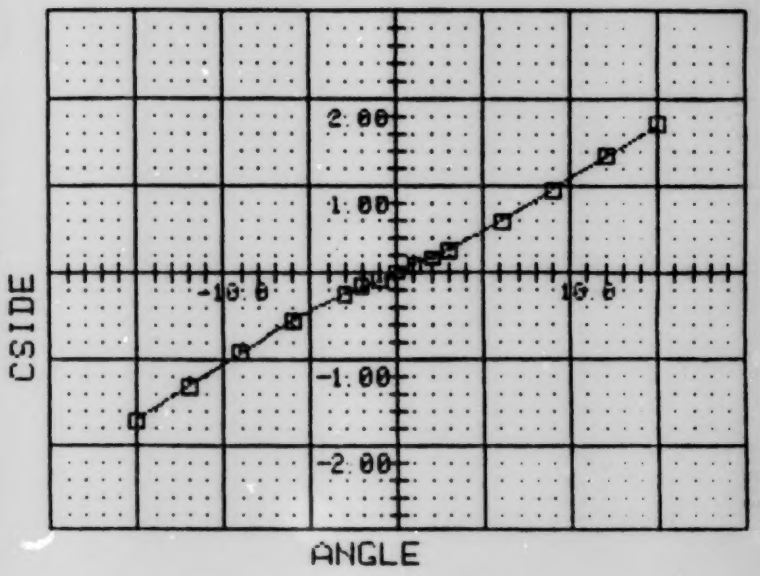
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.03	-2.765	1.830	-1.718	5.002	-0.773	1.106	1.11
-11.98	-1.988	1.367	-1.322	4.296	-0.591	1.063	1.09
-9.03	-1.326	0.976	-0.934	3.606	-0.392	1.005	1.08
-6.00	-0.734	0.554	-0.559	2.848	-0.239	0.919	1.07
-3.01	-0.306	0.307	-0.252	2.202	-0.130	0.830	1.06
-2.04	-0.197	0.179	-0.166	2.054	-0.109	0.792	1.06
-1.02	-0.104	0.042	-0.094	2.041	-0.106	0.788	1.05
0.00	0.001	-0.035	-0.008	2.033	-0.098	0.788	1.05
1.00	0.101	-0.098	0.073	2.103	-0.106	0.804	1.06
2.00	0.198	-0.158	0.154	2.199	-0.116	0.823	1.06
3.04	0.313	-0.242	0.251	2.346	-0.136	0.848	1.06
6.05	0.769	-0.608	0.575	2.978	-0.241	0.938	1.07
9.01	1.336	-0.995	0.944	3.662	-0.378	1.011	1.08
12.02	2.018	-1.367	1.342	4.343	-0.541	1.060	1.09
15.00	2.720	-1.755	1.710	4.945	-0.722	1.097	1.11

Wind Averaged Drag Coefficient at 55. mph = 0.902

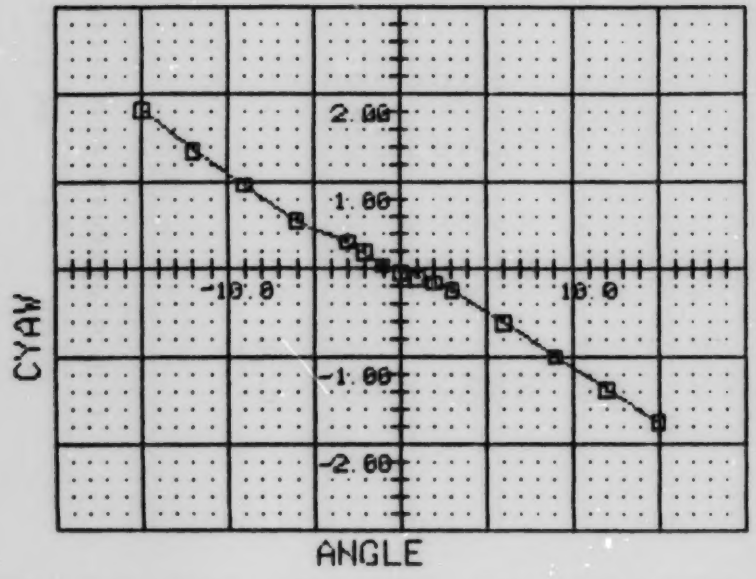
Run 16

ASTRO 95, FRONT 2





B41



RUN NUMBER 17 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, FRONT 1A AND 2

18-MAR-83 14:00:47 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

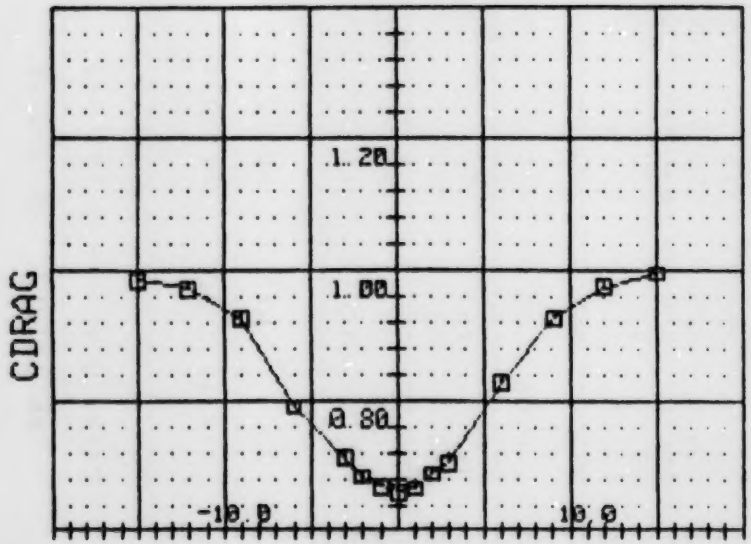
Velocity= 237.2 ft/sec Re= 1.211

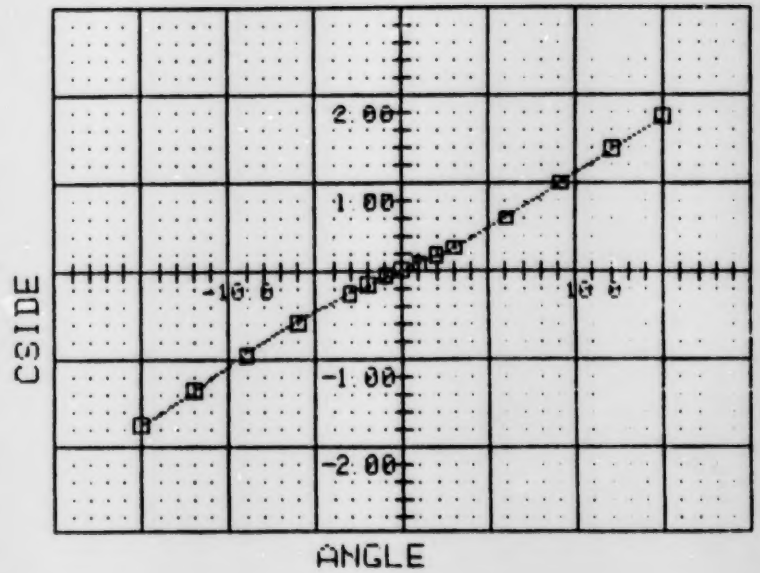
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.03	-2.937	1.846	-1.769	4.941	-0.623	0.983	1.10
-12.02	-2.189	1.555	-1.370	4.343	-0.413	0.970	1.09
-9.02	-1.478	1.221	-0.958	3.711	-0.235	0.924	1.07
-6.00	-0.826	0.517	-0.589	2.896	-0.138	0.789	1.06
-3.02	-0.350	0.225	-0.257	2.306	-0.043	0.711	1.05
-2.02	-0.226	0.117	-0.169	2.180	-0.022	0.682	1.05
-0.93	-0.097	0.033	-0.073	2.133	-0.003	0.667	1.05
0.00	0.005	-0.025	0.001	2.135	-0.004	0.659	1.05
1.00	0.114	-0.087	0.079	2.161	-0.011	0.665	1.05
1.99	0.228	-0.161	0.162	2.250	-0.025	0.687	1.05
2.98	0.342	-0.169	0.260	2.358	-0.053	0.703	1.05
6.01	0.851	-0.689	0.590	3.064	-0.104	0.827	1.06
9.11	1.492	-1.174	0.991	3.779	-0.217	0.925	1.08
12.04	2.175	-1.563	1.369	4.360	-0.329	0.973	1.09
15.02	2.891	-1.879	1.743	4.909	-0.534	0.994	1.10

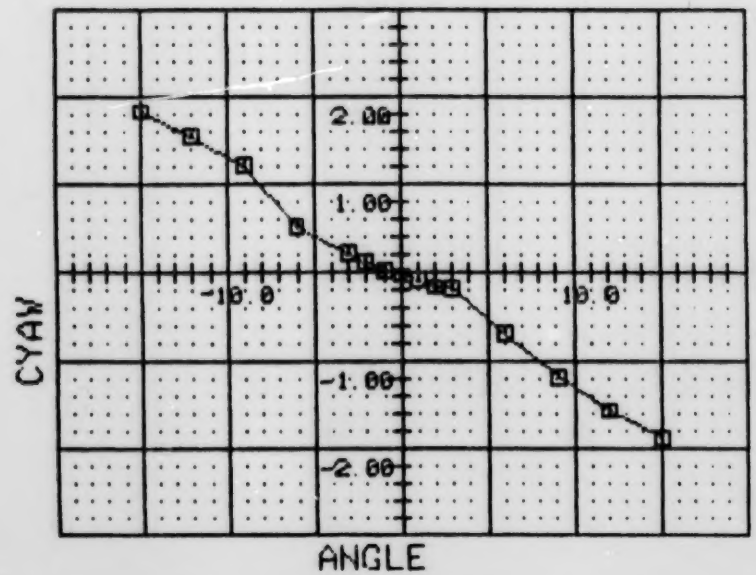
Wind Averaged Drag Coefficient at 55. mph = 0.781

Run 17

ASTRO 95, FRONT 1A AND 2







B43

RUN NUMBER 18 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, 1A ON CAB ROOF AND 2

18-MAR-83 14:20:48 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

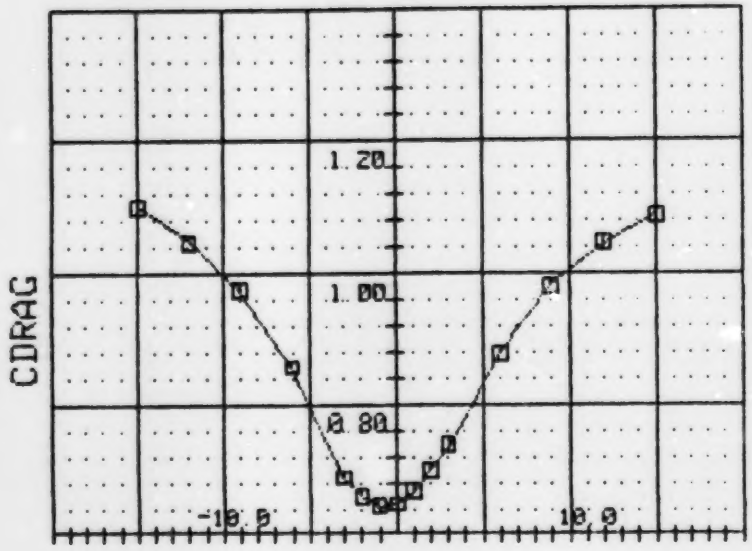
Velocity= 237.7 ft/sec Re= 1.214

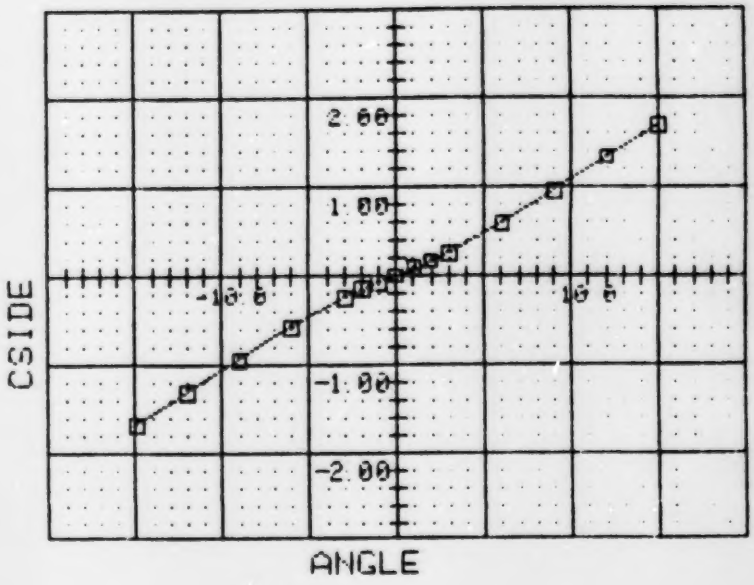
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	GC/Q
-14.95	-2.976	2.076	-1.692	5.181	-0.509	1.099	1.11
-11.99	-2.231	1.752	-1.330	4.559	-0.317	1.046	1.09
-9.02	-1.531	1.337	-0.958	3.915	-0.182	0.973	1.08
-6.02	-0.886	0.769	-0.590	3.184	-0.079	0.856	1.06
-3.00	-0.365	0.184	-0.255	2.419	-0.026	0.687	1.05
-1.99	-0.235	0.095	-0.169	2.250	-0.006	0.659	1.05
-1.01	-0.118	0.022	-0.087	2.169	0.010	0.644	1.04
0.00	-0.005	-0.055	-0.010	2.195	0.009	0.647	1.04
1.02	0.103	-0.131	0.061	2.280	0.005	0.665	1.05
1.99	0.237	-0.245	0.156	2.442	-0.008	0.698	1.05
3.03	0.369	-0.363	0.249	2.639	-0.024	0.738	1.05
6.02	0.883	-0.809	0.584	3.269	-0.074	0.877	1.07
8.99	1.492	-1.232	0.951	3.927	-0.169	0.979	1.08
12.01	2.196	-1.560	1.327	4.557	-0.306	1.044	1.09
15.02	2.898	-1.876	1.679	5.136	-0.491	1.087	1.11

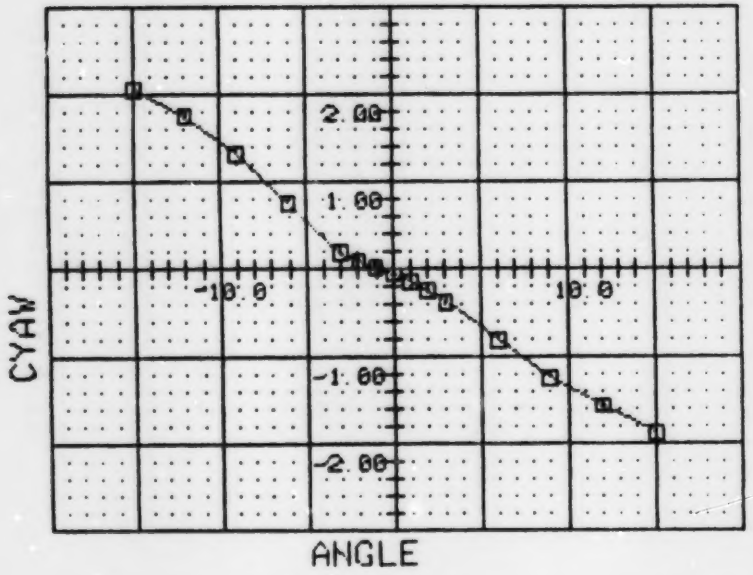
Wind Averaged Drag Coefficient at 55. mph = 0.812

Run 18

ASTRO 95. 1A ON CAB ROOF AND 2







B45

RUN NUMBER 19 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, 1A ON CAB ROOF

18-MAR-83 14:33:37 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

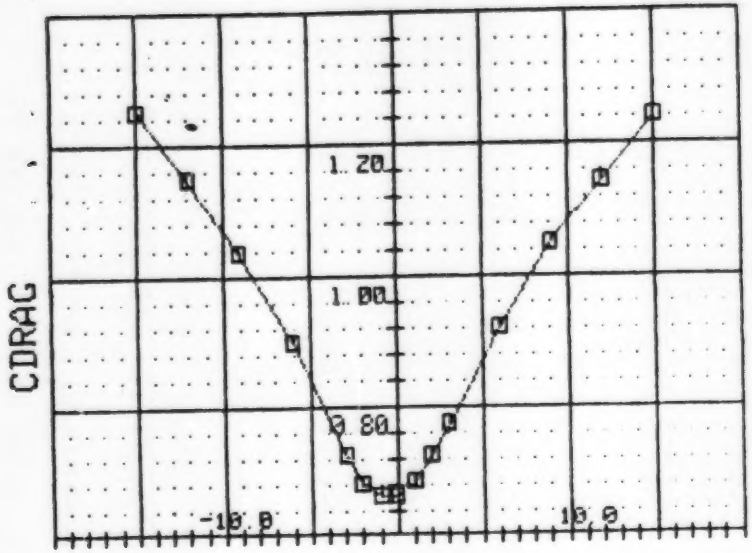
Velocity= 239.2 ft/sec Re= 1.221

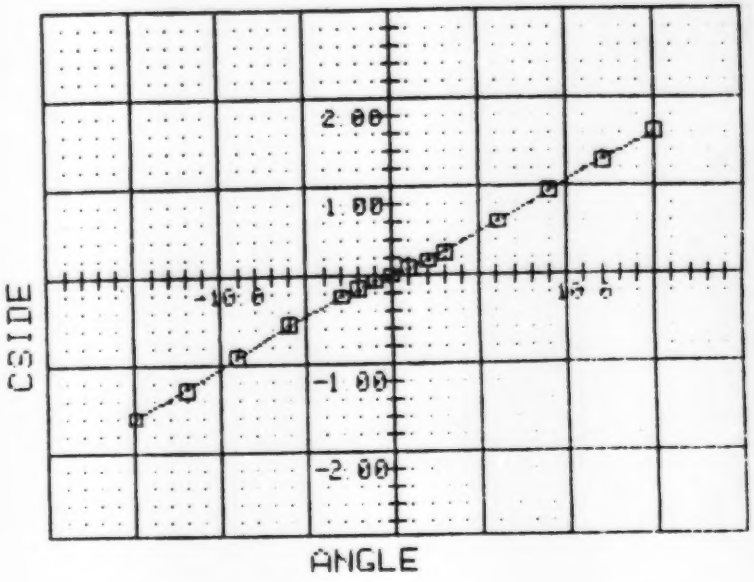
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-14.99	-3.021	2.453	-1.615	5.581	-0.448	1.251	1.12
-12.00	-2.259	2.034	-1.283	4.862	-0.311	1.147	1.10
-9.07	-1.564	1.598	-0.936	4.136	-0.183	1.038	1.08
-6.00	-0.891	0.997	-0.573	3.369	-0.093	0.898	1.07
-2.96	-0.373	0.346	-0.247	2.621	-0.054	0.725	1.05
-2.00	-0.237	0.205	-0.163	2.415	-0.047	0.682	1.05
-0.97	-0.112	0.063	-0.080	2.291	-0.031	0.661	1.05
-0.02	-0.005	-0.055	-0.011	2.298	-0.029	0.662	1.05
0.97	0.108	-0.186	0.063	2.409	-0.037	0.684	1.05
2.01	0.245	-0.335	0.154	2.601	-0.045	0.724	1.05
3.03	0.384	-0.496	0.249	2.815	-0.057	0.772	1.05
6.05	0.916	-1.031	0.588	3.499	-0.093	0.920	1.07
9.01	1.529	-1.495	0.930	4.212	-0.170	1.050	1.08
12.02	2.226	-1.877	1.287	4.873	-0.282	1.143	1.10
15.02	2.951	-2.330	1.598	5.495	-0.417	1.241	1.12

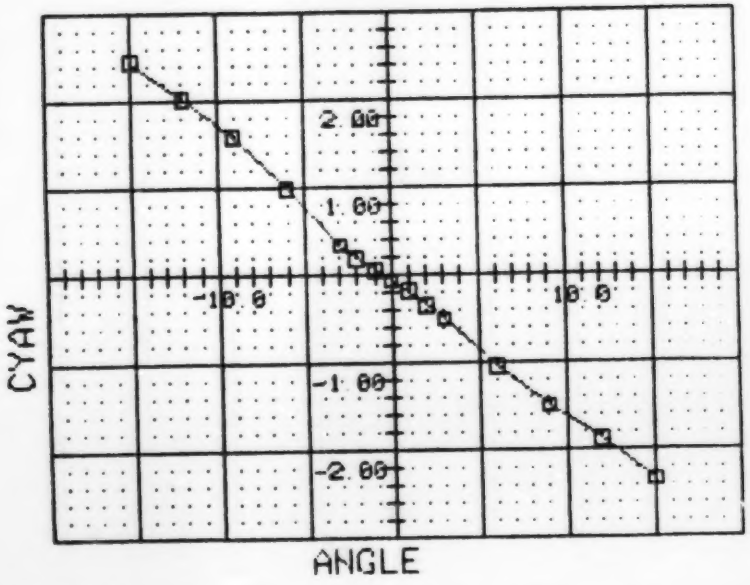
Wind Averaged Drag Coefficient at 55. mph = 0.851

Run 19

ASTRO 95, 1A ON CAB ROOF







B47

RUN NUMBER 20 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, STANDARD FRONT, 7 REAR

18-MAR-83 14:45:38 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

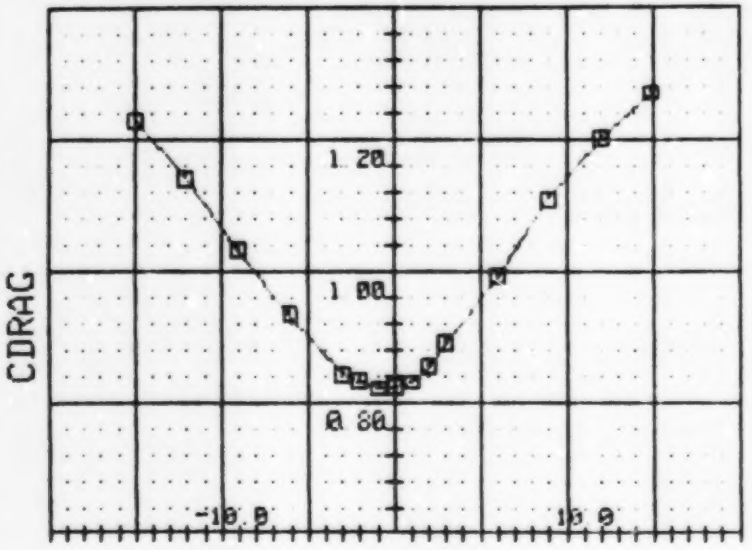
Velocity= 238.7 ft/sec Re= 1.219

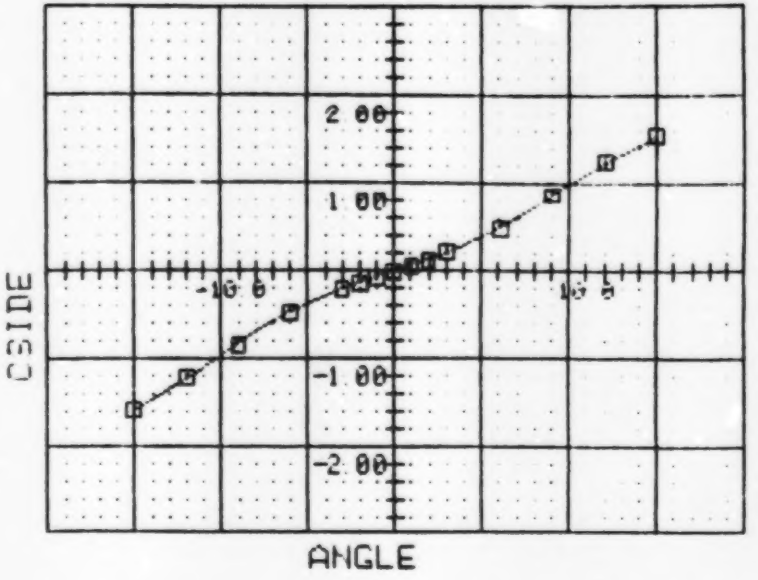
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.03	-2.672	1.995	-1.600	5.295	-0.860	1.229	1.12
-12.02	-1.930	1.572	-1.234	4.509	-0.726	1.140	1.10
-9.01	-1.221	1.074	-0.857	3.606	-0.531	1.032	1.08
-6.02	-0.636	0.611	-0.490	2.784	-0.348	0.933	1.07
-3.01	-0.286	0.228	-0.227	2.212	-0.254	0.842	1.06
-2.00	-0.194	0.139	-0.152	2.093	-0.230	0.830	1.06
-0.96	-0.101	-0.009	-0.085	2.035	-0.231	0.820	1.06
0.00	-0.023	-0.076	-0.023	2.037	-0.230	0.822	1.06
0.99	0.058	-0.150	0.046	2.080	-0.238	0.829	1.06
1.99	0.147	-0.254	0.119	2.192	-0.252	0.853	1.06
3.00	0.245	-0.356	0.198	2.374	-0.274	0.888	1.06
6.05	0.651	-0.719	0.487	3.001	-0.369	0.990	1.07
8.99	1.247	-1.241	0.855	3.856	-0.514	1.109	1.09
12.05	1.929	-1.667	1.231	4.674	-0.645	1.201	1.10
14.97	2.514	-2.078	1.532	5.268	-0.687	1.270	1 12

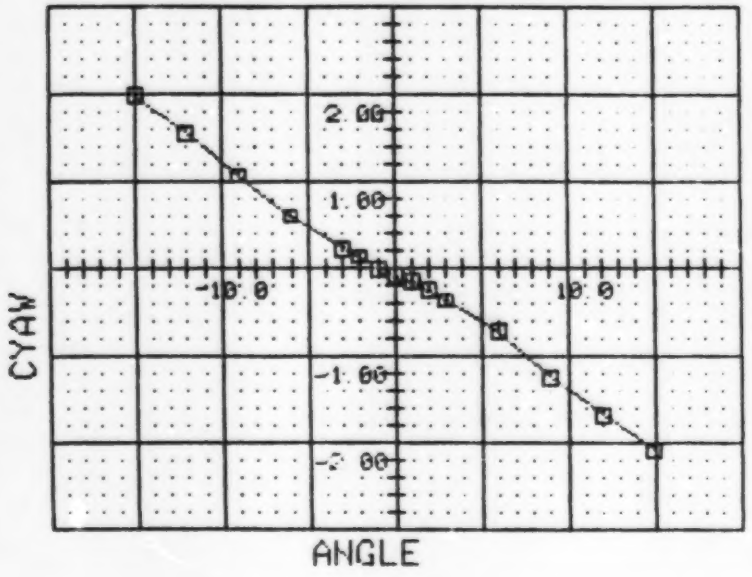
Wind Averaged Drag Coefficient at 55. mph = 0.938

Run 20

ASTRO 95, STANDARD FRONT, 7 REAR







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RUN NUMBER 21 REPORT NUMBER 388

LES PNEUS METRIX

ASTRO 95, 1B CYLINDER

18-MAR-83 15:03:00 Tare No. 1

Frontal Area=106.0 ft**2 Reference Length= 8.0 ft

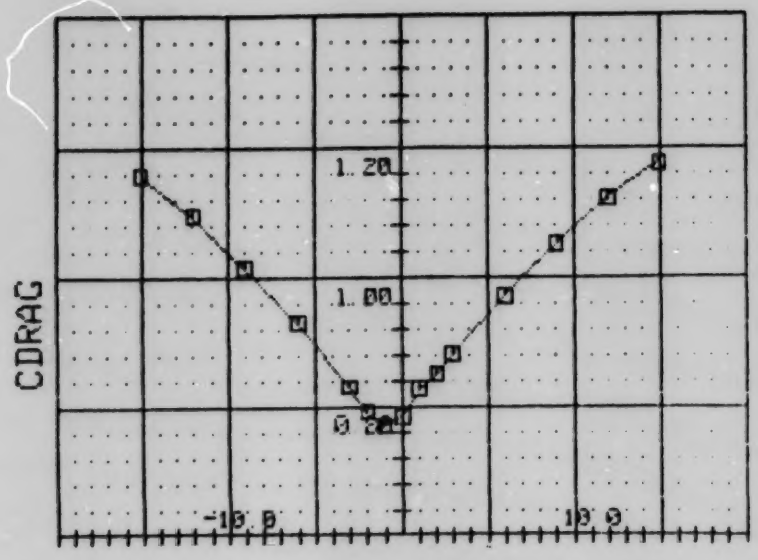
Velocity= 238.2 ft/sec Re= 1.216

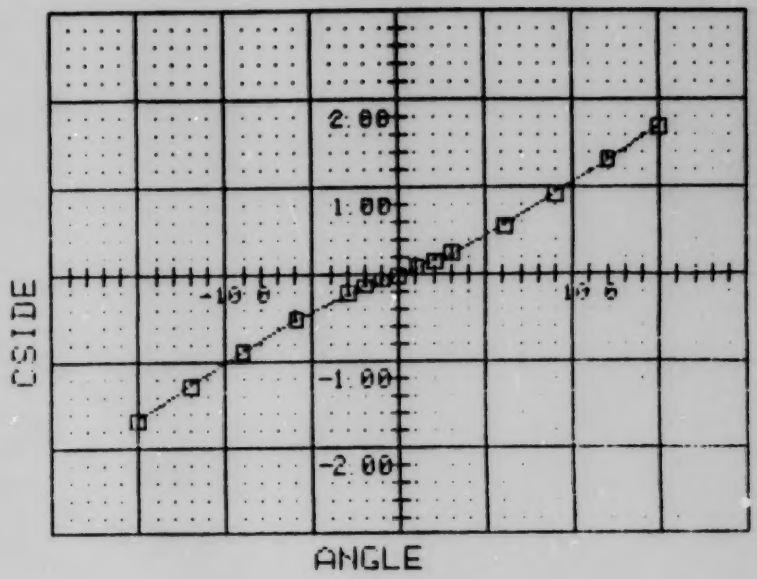
Yaw Angle (deg)	CRM	CYM	CS	CPM	CL	CD	QC/Q
-15.04	-2.778	1.867	-1.687	5.178	-0.774	1.156	1.11
-12.00	-1.975	1.405	-1.288	4.397	-0.627	1.093	1.10
-9.00	-1.275	0.989	-0.894	3.591	-0.449	1.013	1.08
-5.96	-0.697	0.616	-0.532	2.827	-0.271	0.929	1.07
-2.98	-0.308	0.391	-0.229	2.263	-0.117	0.830	1.06
-1.99	-0.192	0.263	-0.142	2.105	-0.090	0.790	1.05
-1.02	-0.099	0.090	-0.078	2.020	-0.095	0.769	1.05
-0.01	-0.014	-0.099	-0.019	2.041	-0.113	0.784	1.05
0.99	0.083	-0.167	0.064	2.090	-0.150	0.826	1.06
2.04	0.183	-0.240	0.152	2.213	-0.170	0.849	1.06
3.00	0.284	-0.309	0.239	2.382	-0.194	0.880	1.06
6.07	0.729	-0.592	0.546	3.063	-0.294	0.971	1.07
9.01	1.316	-0.964	0.919	3.815	-0.459	1.051	1.08
11.99	2.018	-1.336	1.304	4.576	-0.628	1.122	1.10
14.99	2.776	-1.779	1.681	5.258	-0.763	1.175	1.11

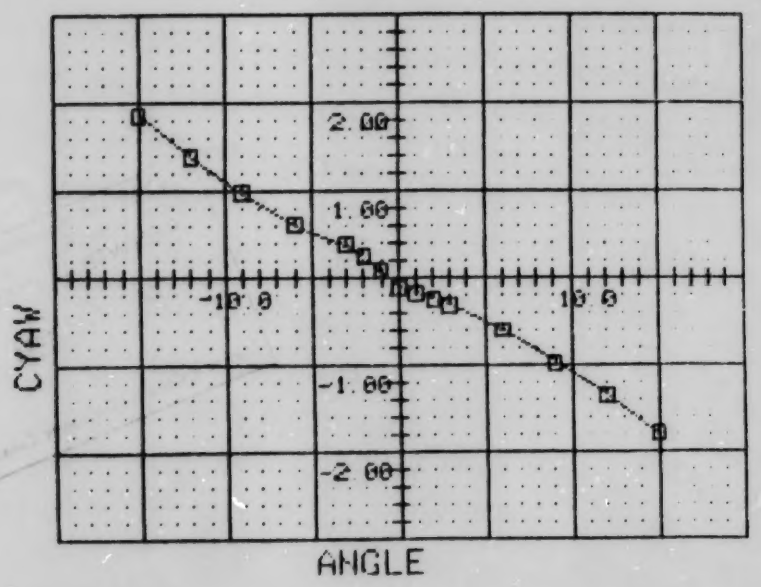
Wind Averaged Drag Coefficient at 55. mph = 0.920

Run 21

ASTRO 95, 1B CYLINDER







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